Calidad de la predicción climática a escala estacional en Europa y procesos implicados

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- Seasonal forecasting: empirical and dynamical
- Operational seasonal forecast system: ECMWF System 3
- Systematic errors
- Skill: correlation
- Sources of predictability and error reduction
- Conclusions

- Focus on one-month lead seasonal forecasts of temperature and precipitation, except for JFM

Sources of seasonal predictability

- Important:
  - ENSO - biggest single signal
  - Other tropical ocean SST - difficult
  - Climate change - important in mid-latitudes
  - Local land surface conditions - soil moisture, snow
  - Atmospheric composition - difficult

- Other factors:
  - Volcanic eruptions - important for large events
  - Mid-latitude ocean temperatures - still somewhat controversial
  - Remote soil moisture/snow cover - not well established
  - Sea-ice anomalies - at least local effects
  - Stratospheric influences - various possibilities
  - Remote tropical atmospheric teleconnections

- Unknown or Unexpected

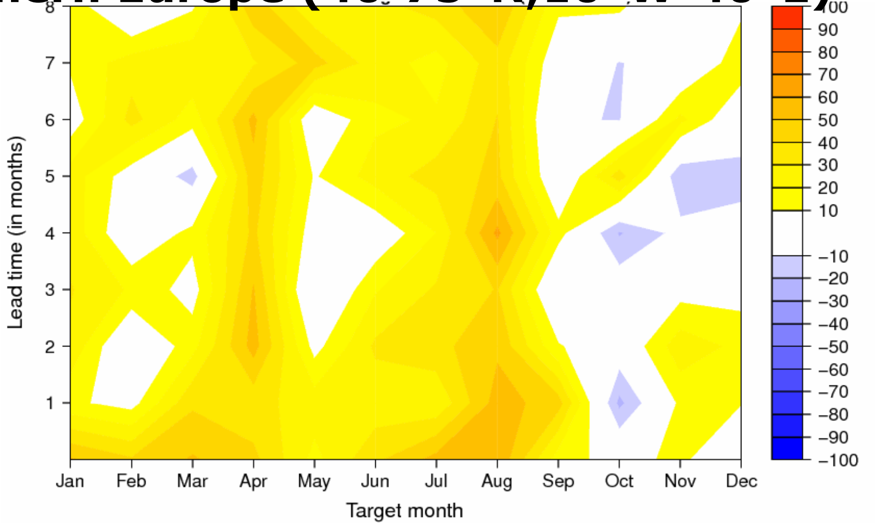
Methods of seasonal forecasting

- Empirical forecasting
  - Use past observational record and statistical methods
  - Works with reality instead of error-prone numerical models ➨
  - Limited number of past cases ➩
  - A non-stationary climate is problematic ➩
  - Can be used as a benchmark ➨
- Two-tier forecast systems
  - First predict SST anomalies (ENSO or global; dynamical or statistical)
  - Use ensemble of atmosphere GCMs to predict global response
  - Systematic model error is an issue
- Single-tier GCM forecasts
  - Include comprehensive range of sources of predictability ➨
  - Predict joint evolution of ocean and atmosphere flow ➨
  - Includes a large range of physical processes ➨
  - Includes uncertainty sources, important for prob. Forecasts ➨
  - Systematic model error is an issue! ➩

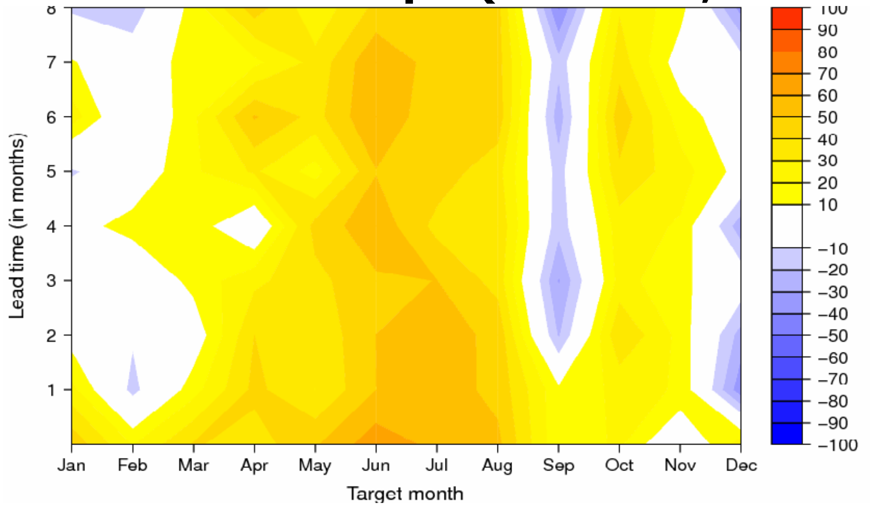
Simple empirical model: persistence

Correlation of a persistence model based on linear regression with GHCN temperature over 1981-2005, with the first regression model using data for 1952-1980.

Northern Europe (40-75°N,10°W-40°E)



Southern Europe (35-45°N,5°W-30°E)



Simple empirical model: persistence

Correlation of a persistence model based on linear regression with GHCN temperature (GPCC precipitation) over 1981-2005, with the first regression model using data for 1952-1980.

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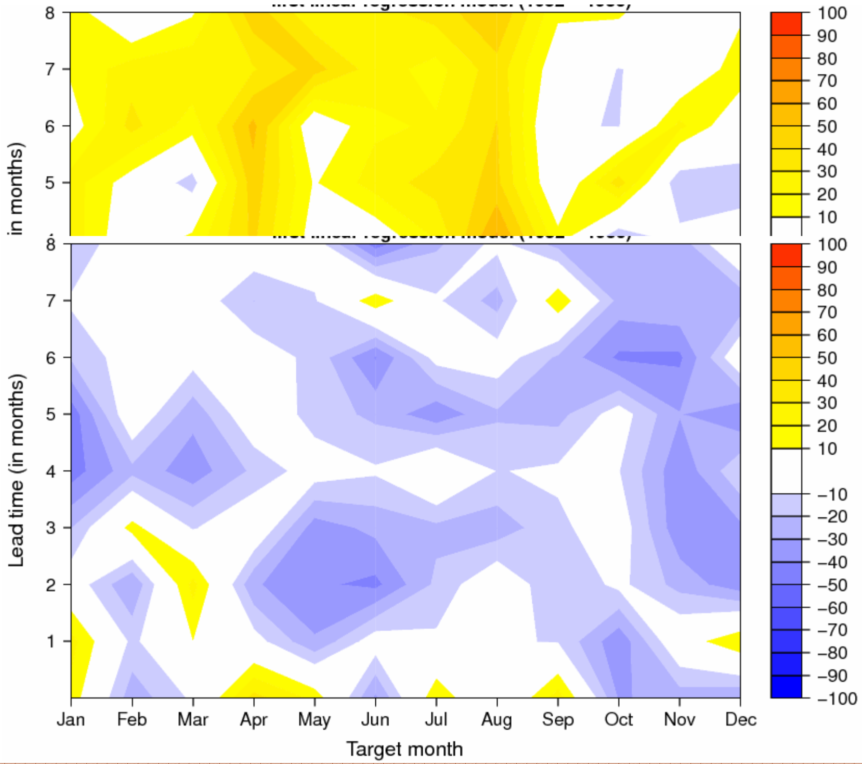
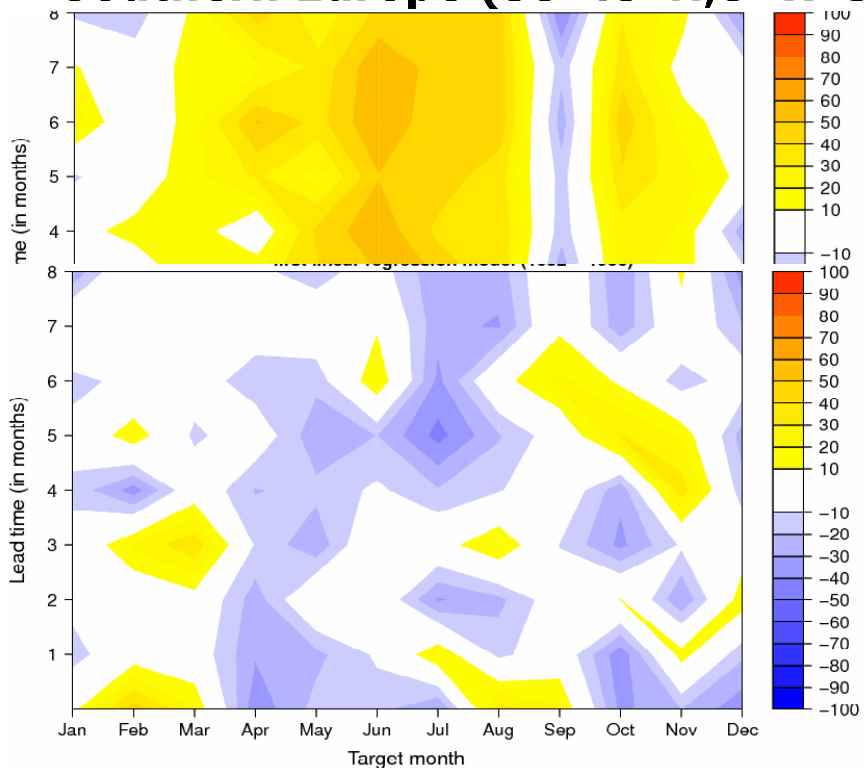
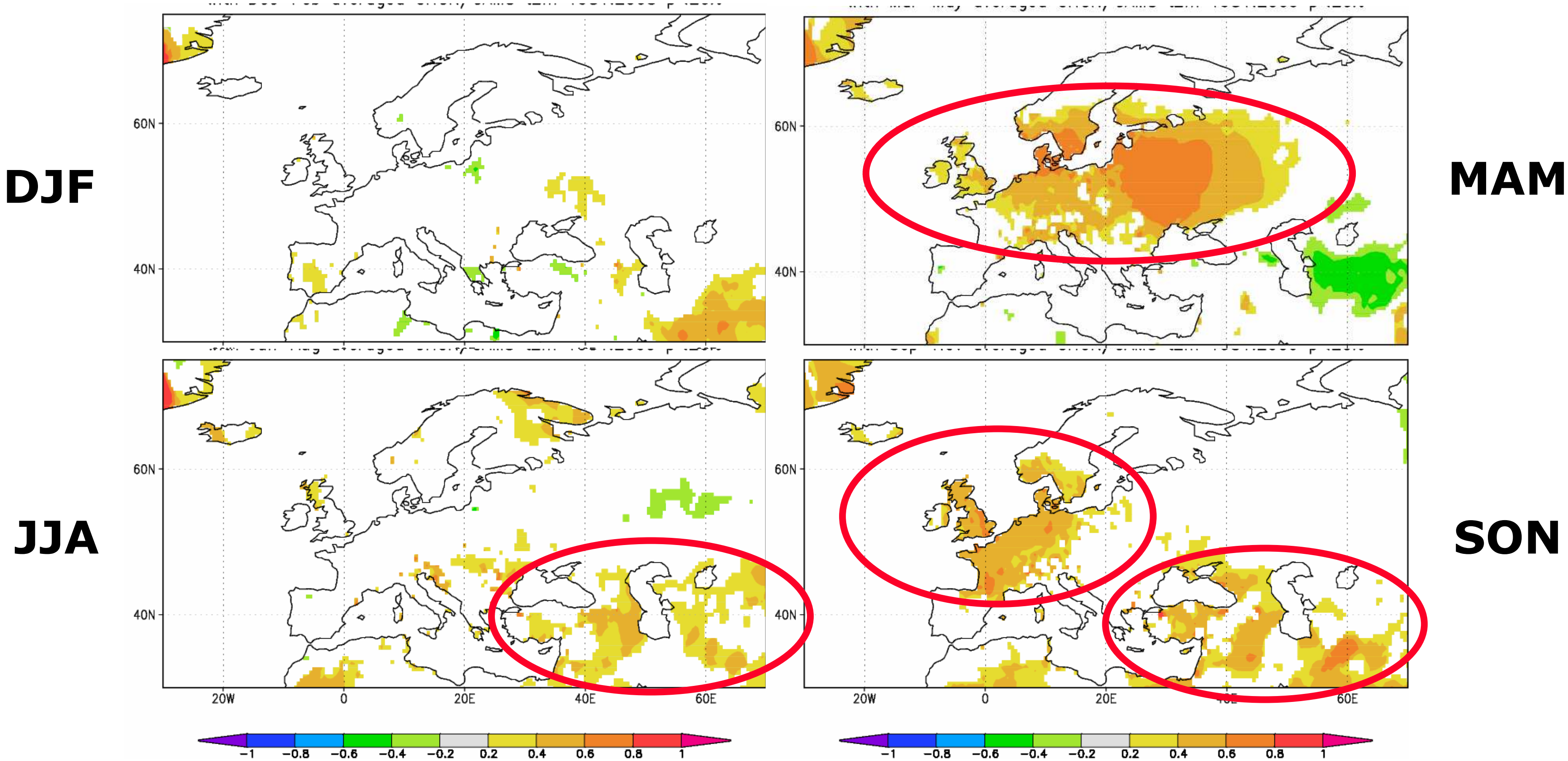


Southern Europe (35-45°N,5°W-30°E)



Temperature skill: persistence

Correlation of GHCN temperature of one-month lead anomaly persistence over 1981-2005. Only values statistically significant with 80% confidence are plotted.



To produce dynamical forecasts

- Build a coupled model
- Prepare initial conditions
- Initialize coupled system
  - o The aim is to start the system close to reality. Accurate SST is particularly important, plus ocean sub-surface. Usually, worry about "imbalances" a posteriori.
- Run an ensemble forecast
  - o Explicitly generate an ensemble on the e.g. 1st of each month, with perturbations to represent the uncertainty *in the initial conditions*; run forecasts for several months.
- Produce probability forecasts from the ensemble
- Apply calibration and combination if significant improvement is found

Ocean re-analysis

- Main Objective: Initialization of seasonal forecasts
  - Historical reanalysis brought up-to-date (11 days behind real time)
  - Source of data for climate variability analysis

Main Features

- ERA-40 daily fluxes (1959-2002) and NWP thereafter
- Retrospective ocean reanalysis back to 1959
- Assimilation of temperature, salinity, altimeter sea level anomalies an global sea level trends.
- 3D OI, salinity along isotherms
- Balance constrains (T/S and geostrophy)
- Sequential assimilation, 10-day analysis cycle

ECMWF's System 3 seasonal forecasts

- Real-time forecasts:
  - 41-member ensemble forecast to 7 months
  - Five-member ocean analysis
  - SST and atmos. perturbations added to each member
  - Initial conditions are valid for 0 GMT on the 1st of a month

  - 11 member ensemble forecast to 13 months
  - Designed to give an 'outlook' for ENSO
  - Only once per quarter (Feb, May, Aug and Nov starts)

- Re-forecasts from 1981-2005 (25 years)
  - 11-member ensemble every month
  - 5 members to 13 months once per quarter
  - The observations have only 1 member, so large ensembles are much less helpful than large numbers of cases.

And there are systematic errors

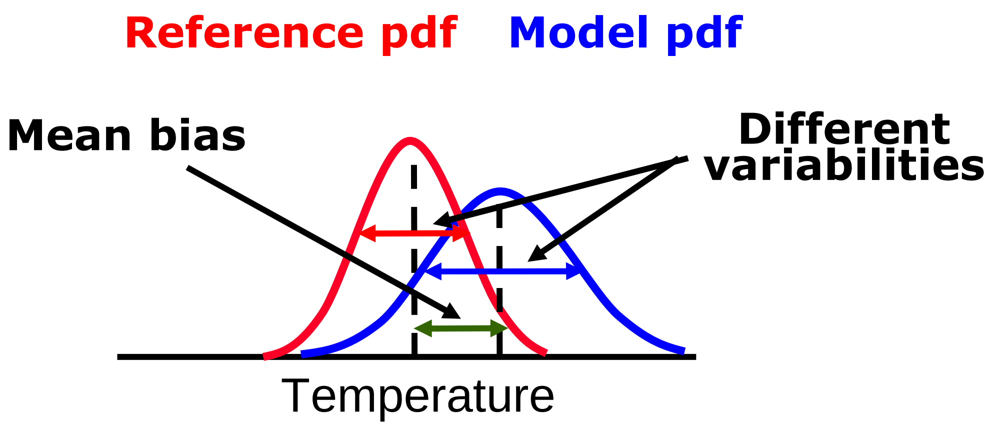
- Model drift is typically comparable to signal
  - Both SST and atmosphere fields
- Forecasts are made *relative* to past model integrations
  - Model climate estimated from 25 years of forecasts (1981-2005), all of which use a 11 member ensemble. Thus the climate has 275 members.
  - Model climate should be considered as a full distribution.
  - Model climate is a function of start date and forecast lead time.
- Implicit assumption of linearity
  - We implicitly assume that a shift in the model forecast relative to the model climate corresponds to the expected shift in a true forecast relative to the true climate, despite differences between model and true climate.
  - Most of the time, the assumption seems to work pretty well. But not always.

Systematic errors in ensemble forecasts

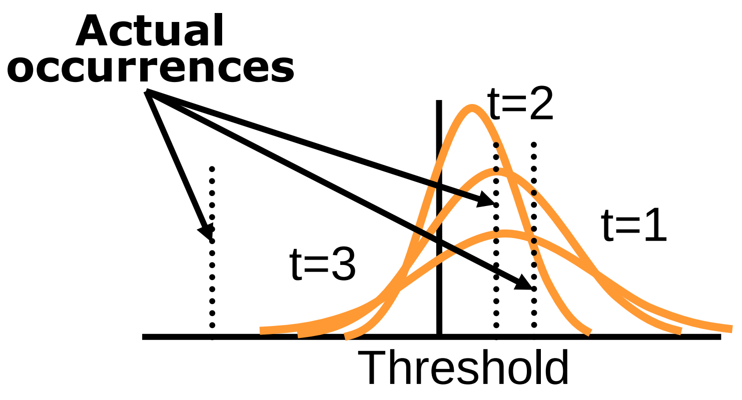
Main systematic errors in dynamical climate forecasts:

- Differences between the model climatological pdf (computed for a lead time from all start dates and ensemble members) and the reference climatological pdf (for the corresponding times of the reference dataset): systematic errors in mean and variability.
- Conditional biases in the forecast pdf: errors in conditional probabilities implying that probability forecasts are not trustworthy. This type of systematic error is best assessed using the reliability diagram.

Differences in climatological pdfs



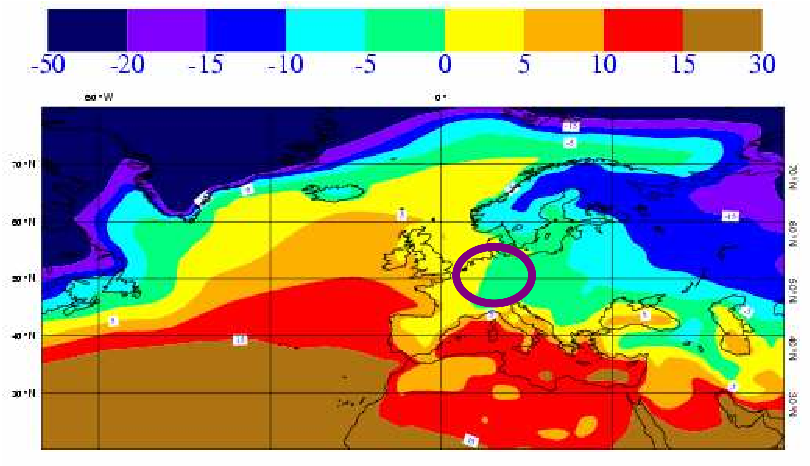
Forecast PDF

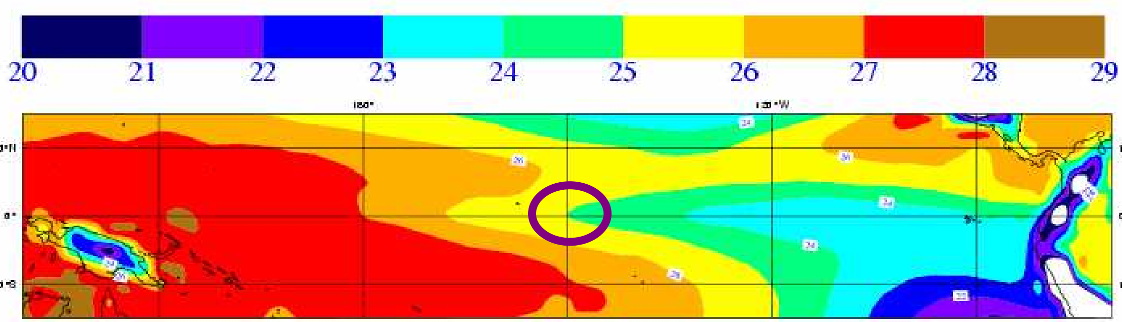


Systematic error: variability

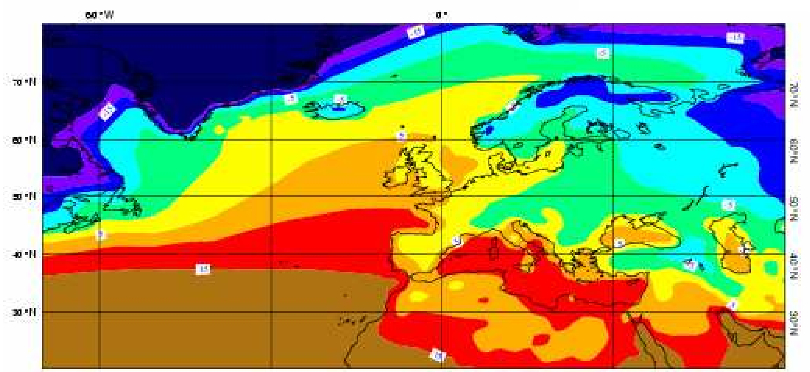
Lower quintile of DJF T2m for ERA-40/OPS (top row) and ECMWF System 3, 1st November start date (bottom row) over 1981-2005 (°C)

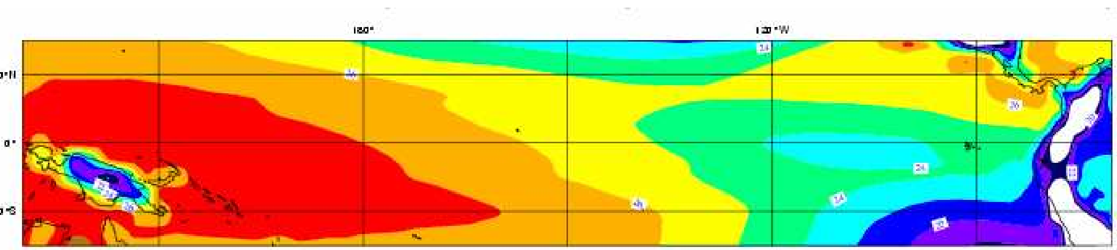
ERA/OPS





ECMWF System 3





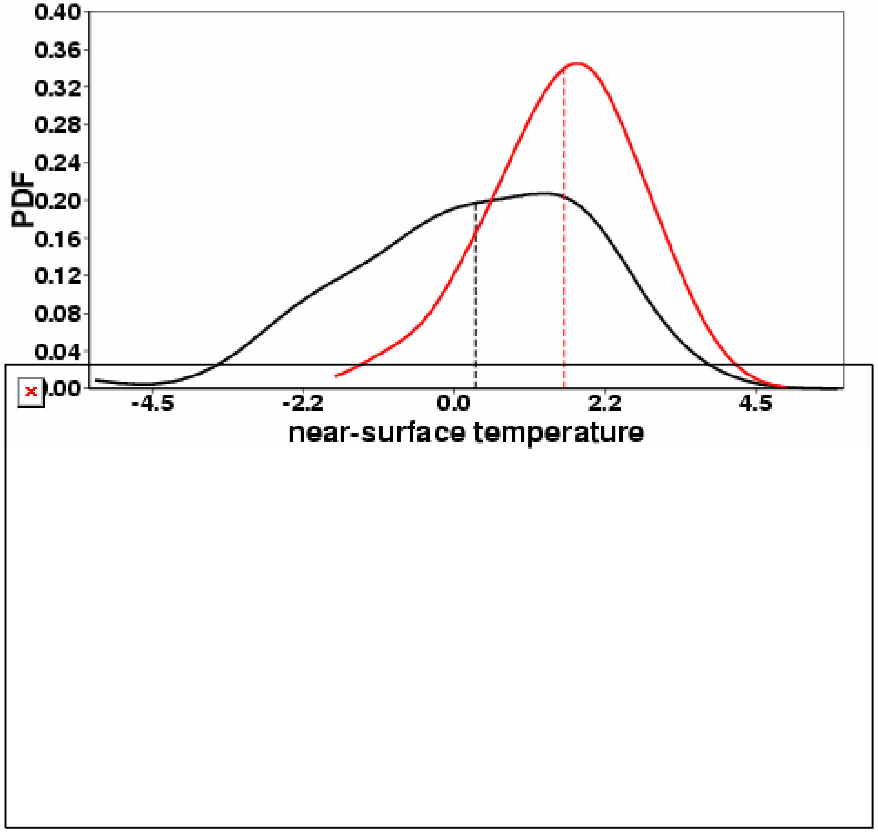
Systematic error: climatological pdf

Climatological PDF of DJF T2m (°C) for ERA-40/OPS and ECMWF System 3, 1st of November start date computed over 1981-2005

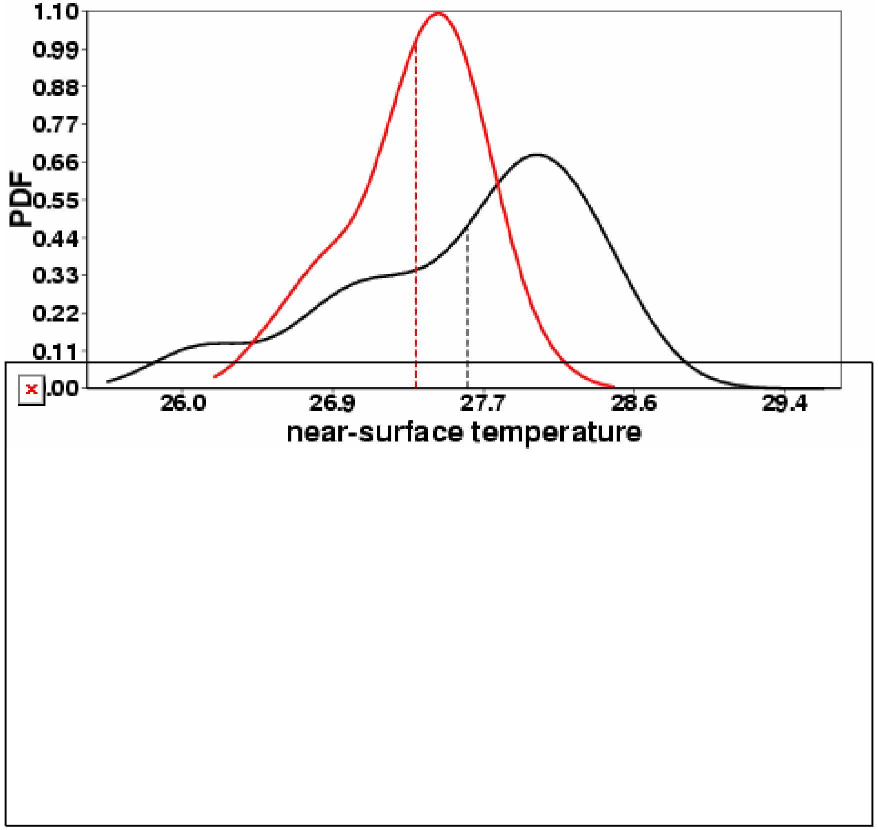
For deterministic forecasts, compute anomalies with respect to the corresponding hindcast

For probabilistic forecasts, compute probabilities with respect to the model mean and reference thresholds (terciles)

Central Europe (50°N, 10°E)



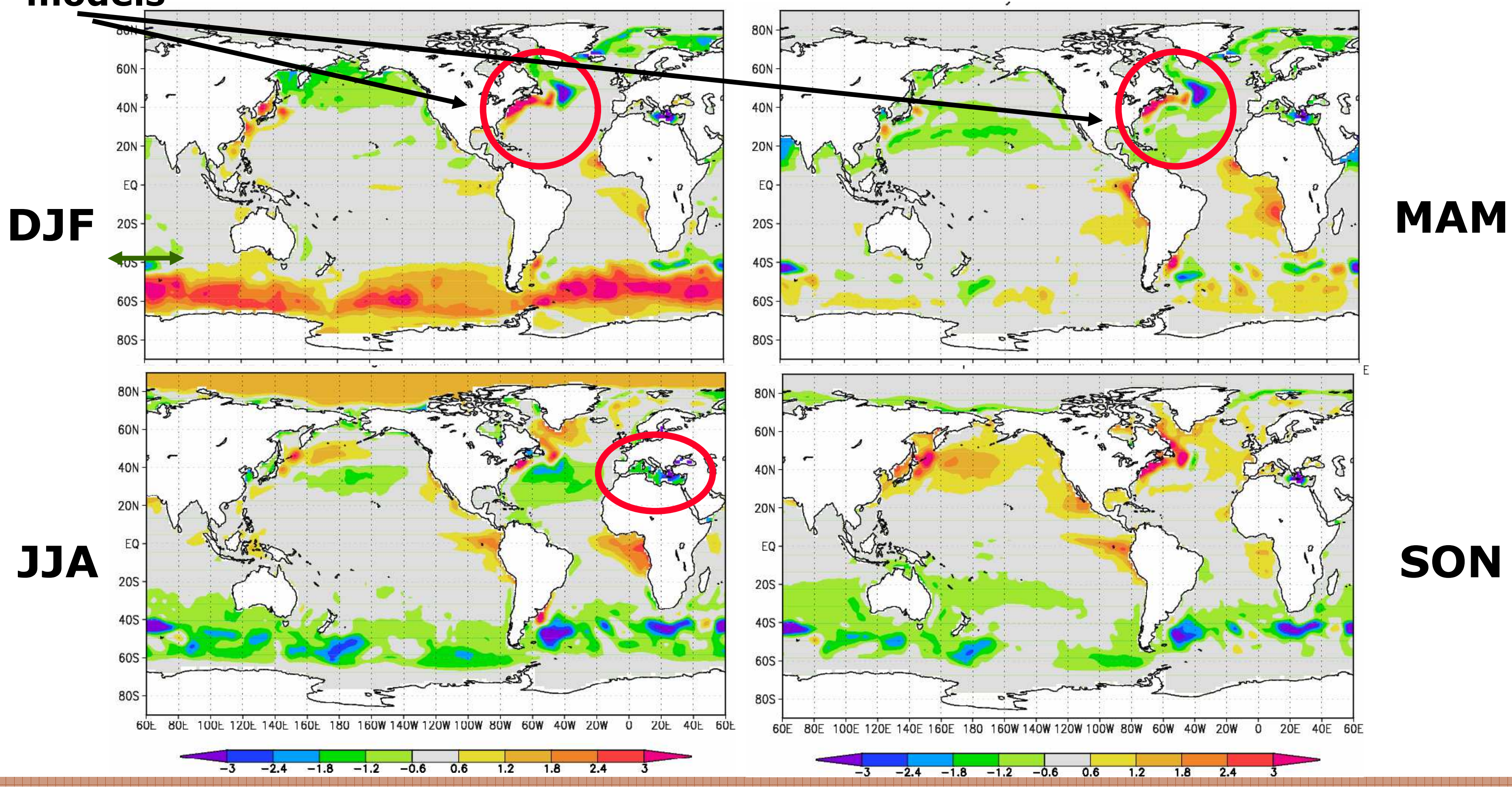
Equatorial Pacific (0, 180°)



Mean error: SSTs

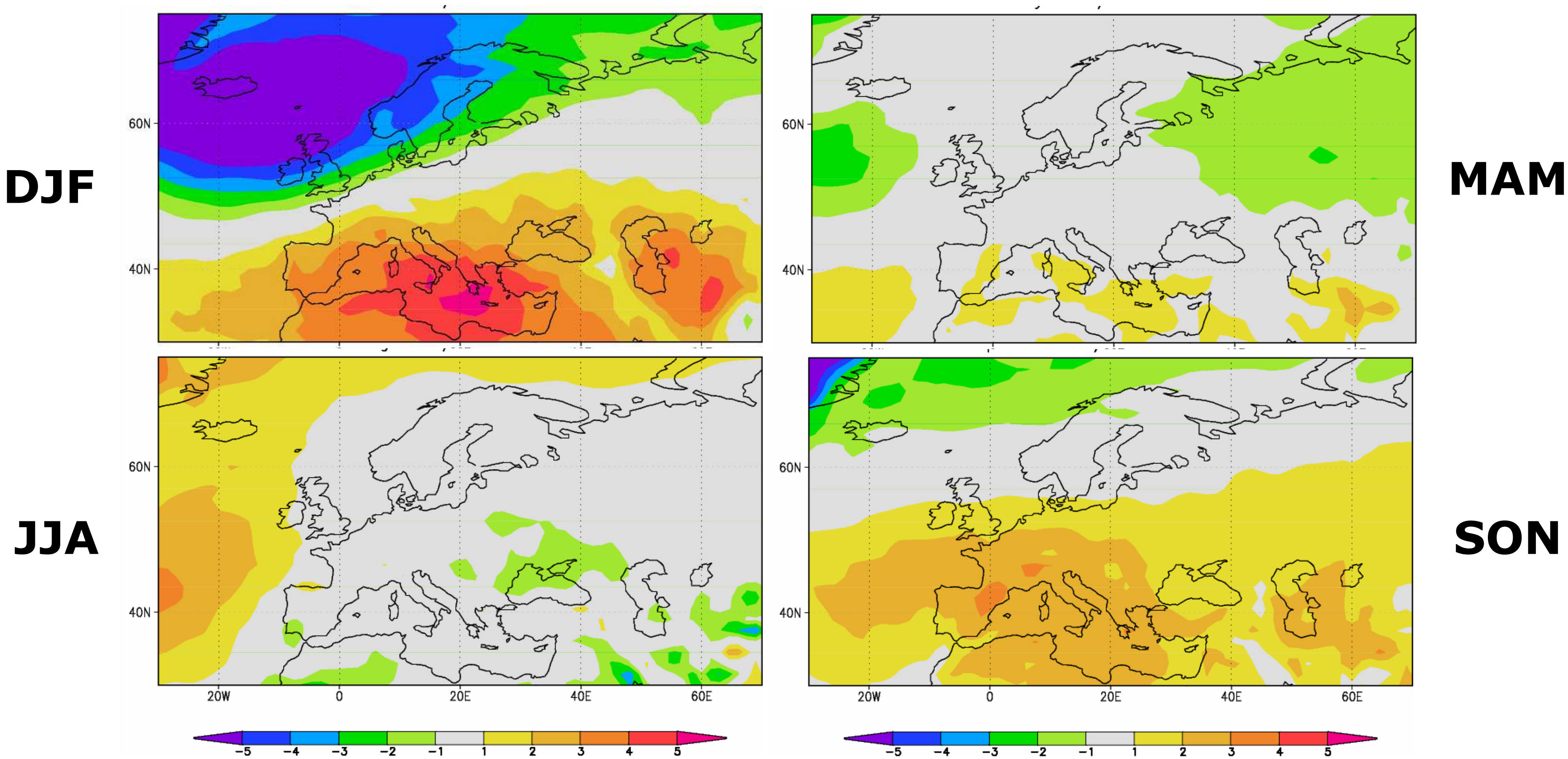
System 3 one-month lead SST (K) bias wrt HadISST1 over 1981-2005.

Typical of CMIP3 models



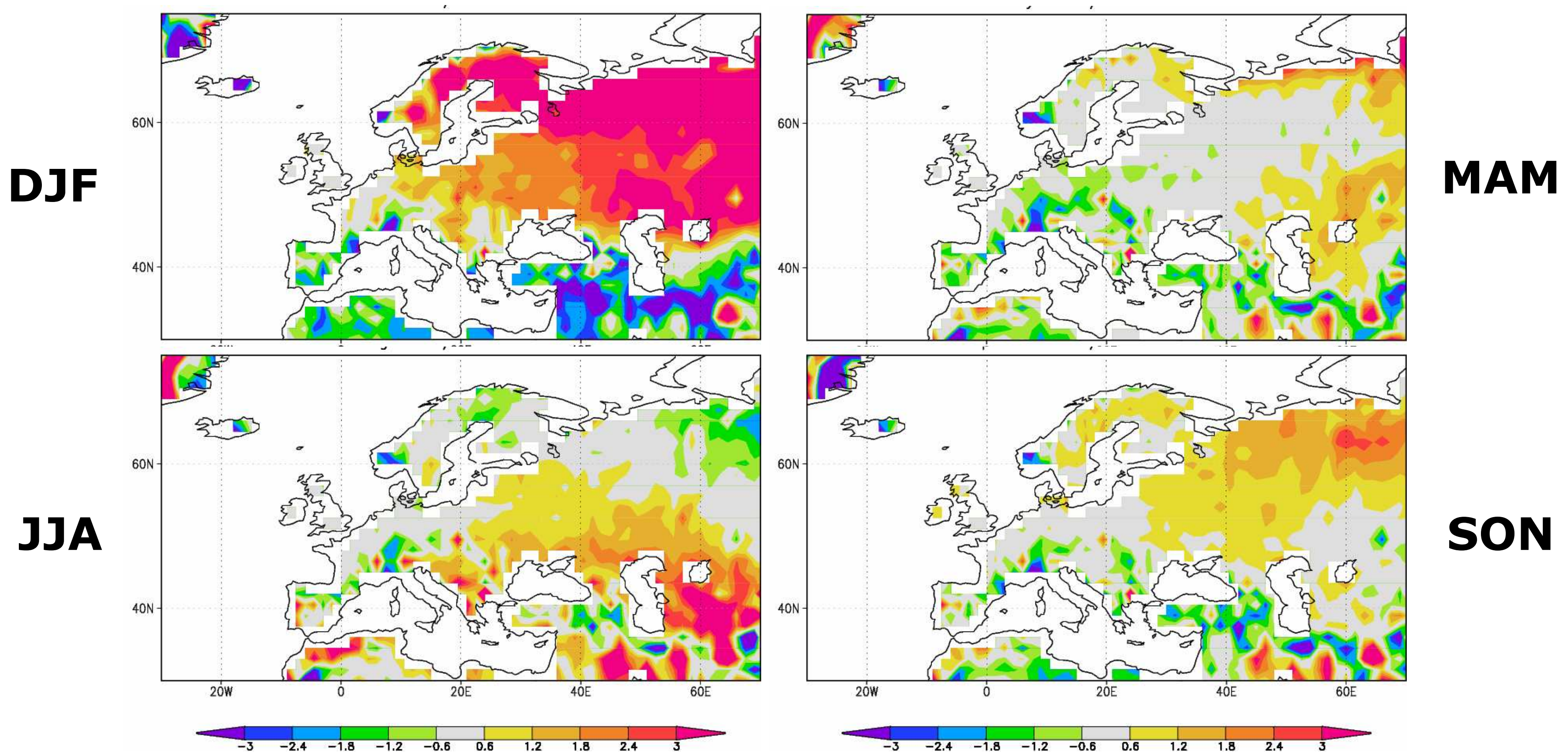
Mean error: MSLP

System 3 one-month lead mean sea level pressure (hPa) bias wrt NCEP/NCAR R1 over 1981-2005.



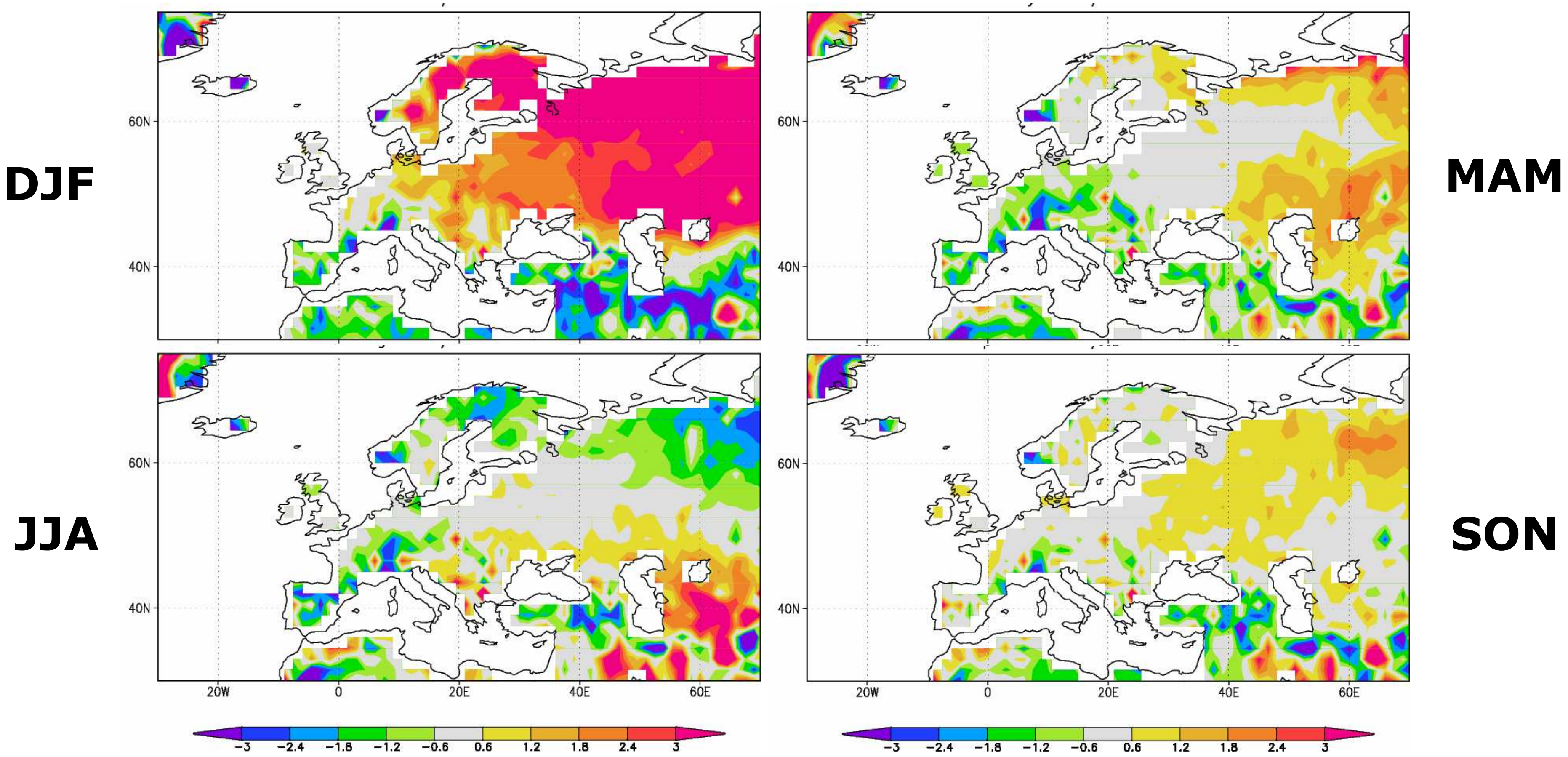
Mean error: T2m

System 3 one-month lead near-surface air temperature (K) bias wrt GHCN over 1981-2005.



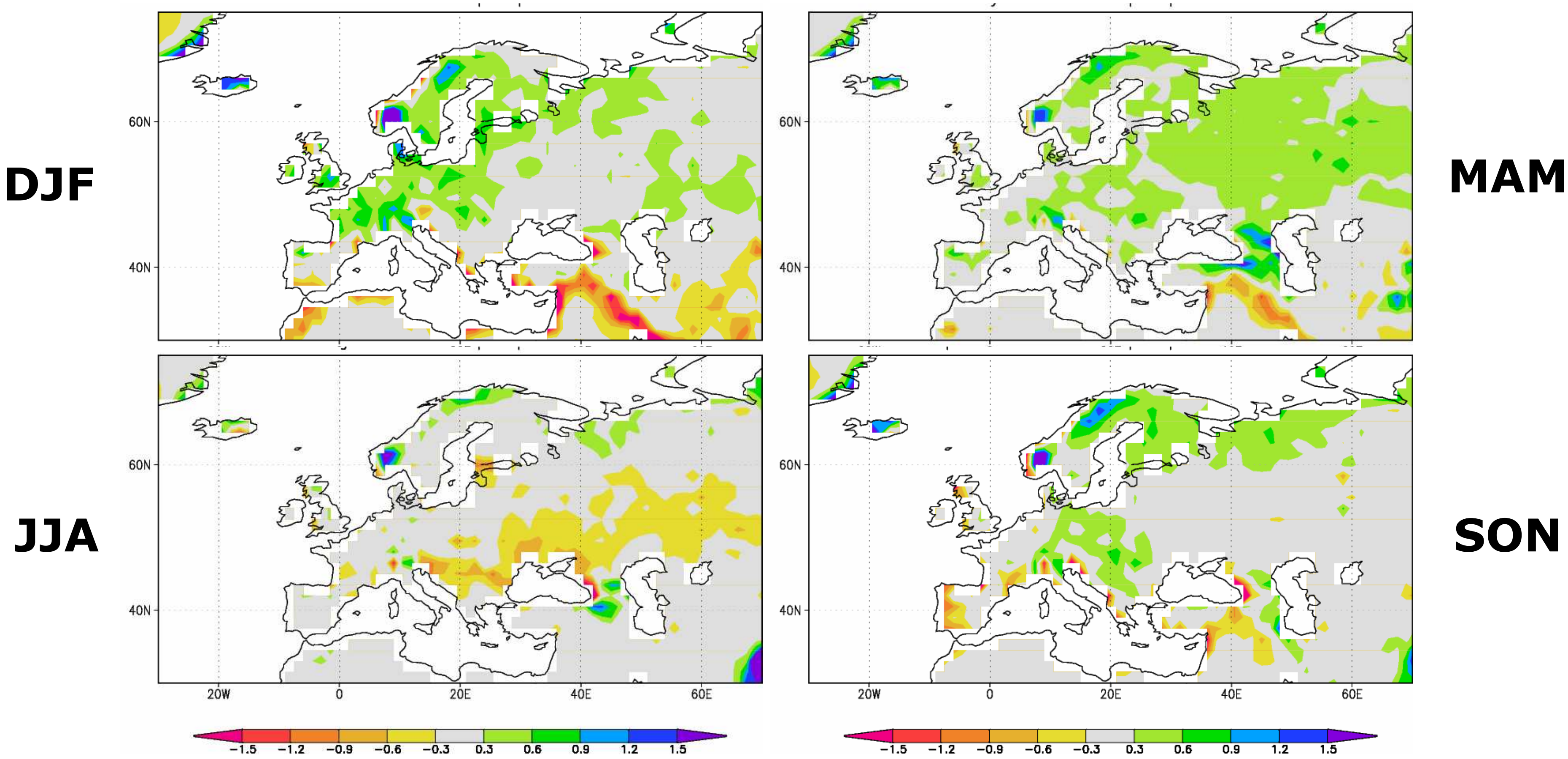
Mean error: T2m

System 3 three-month lead near-surface air temperature (K) bias wrt GHCN over 1981-2005.



Mean error: precipitation

System 3 one-month lead precipitation (mm/day) bias wrt GPCC over 1981-2005.



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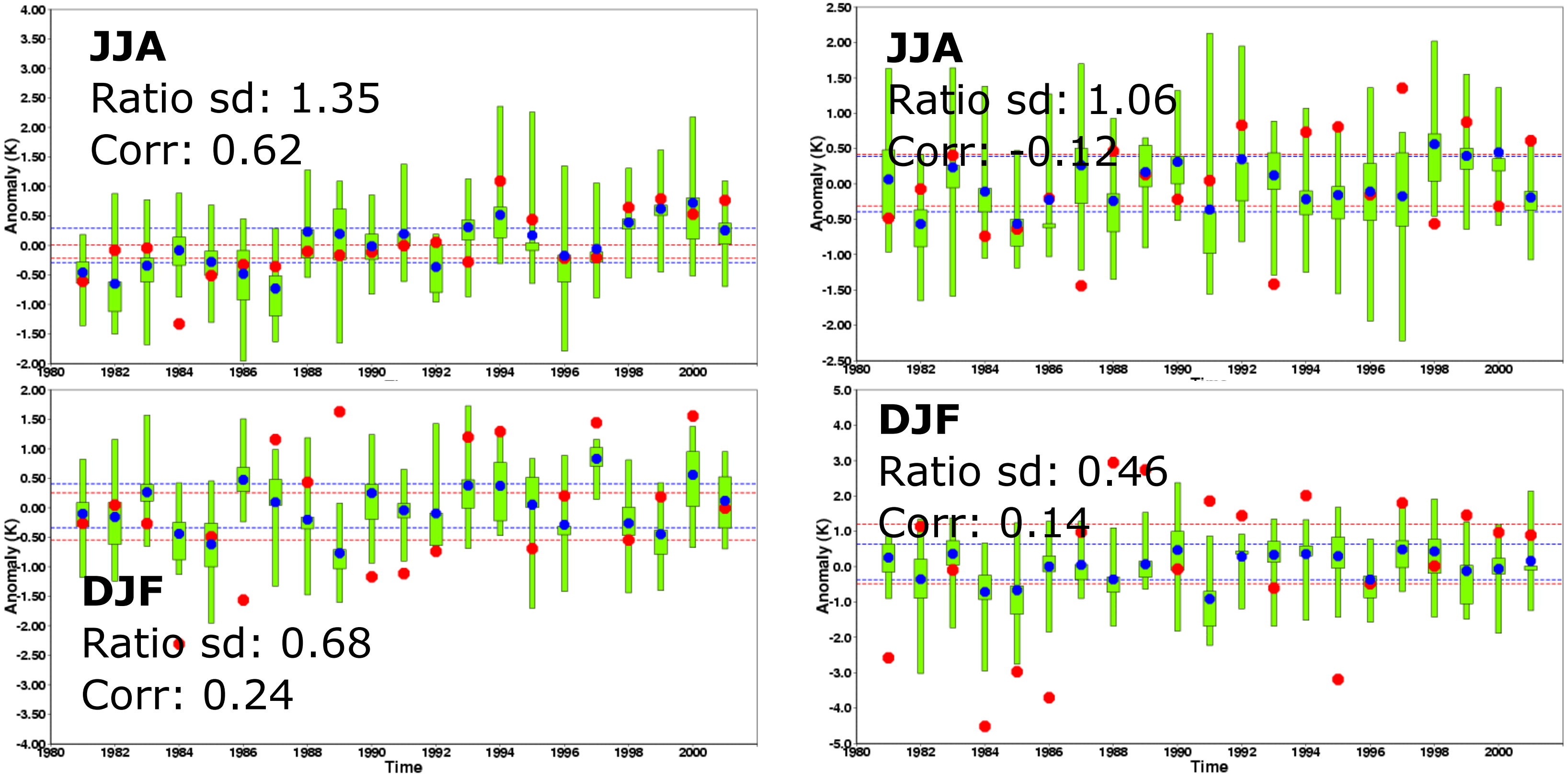
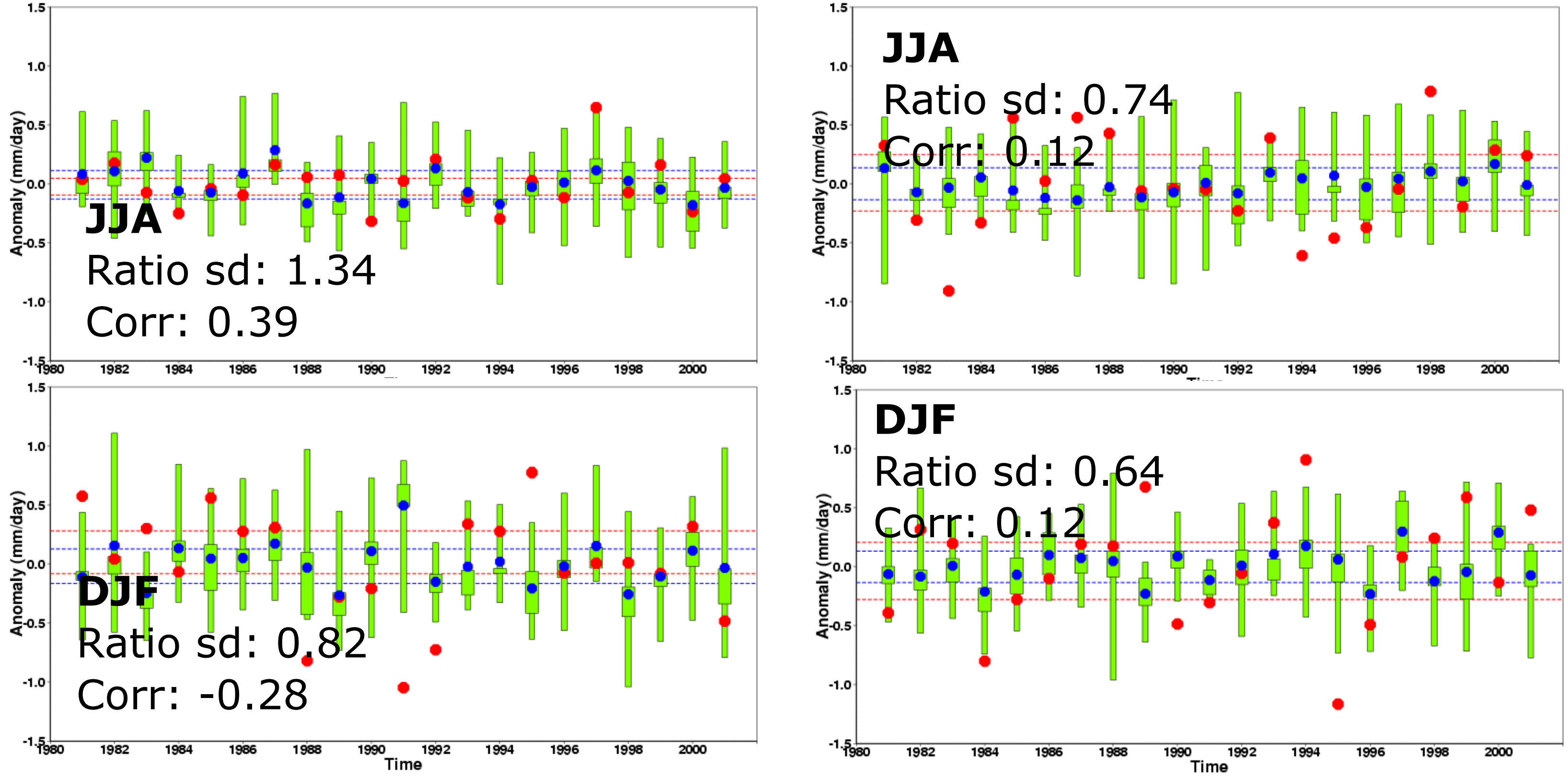
Seasonal re-forecasts for Europe

System 3 temperature re-forecasts for Southern (left) and Northern Europe (right) over 1981-2005. The green box-and-whisker show the ensemble range, the blue dot the ensemble mean and the red dot the ERA40/ERAInt value.



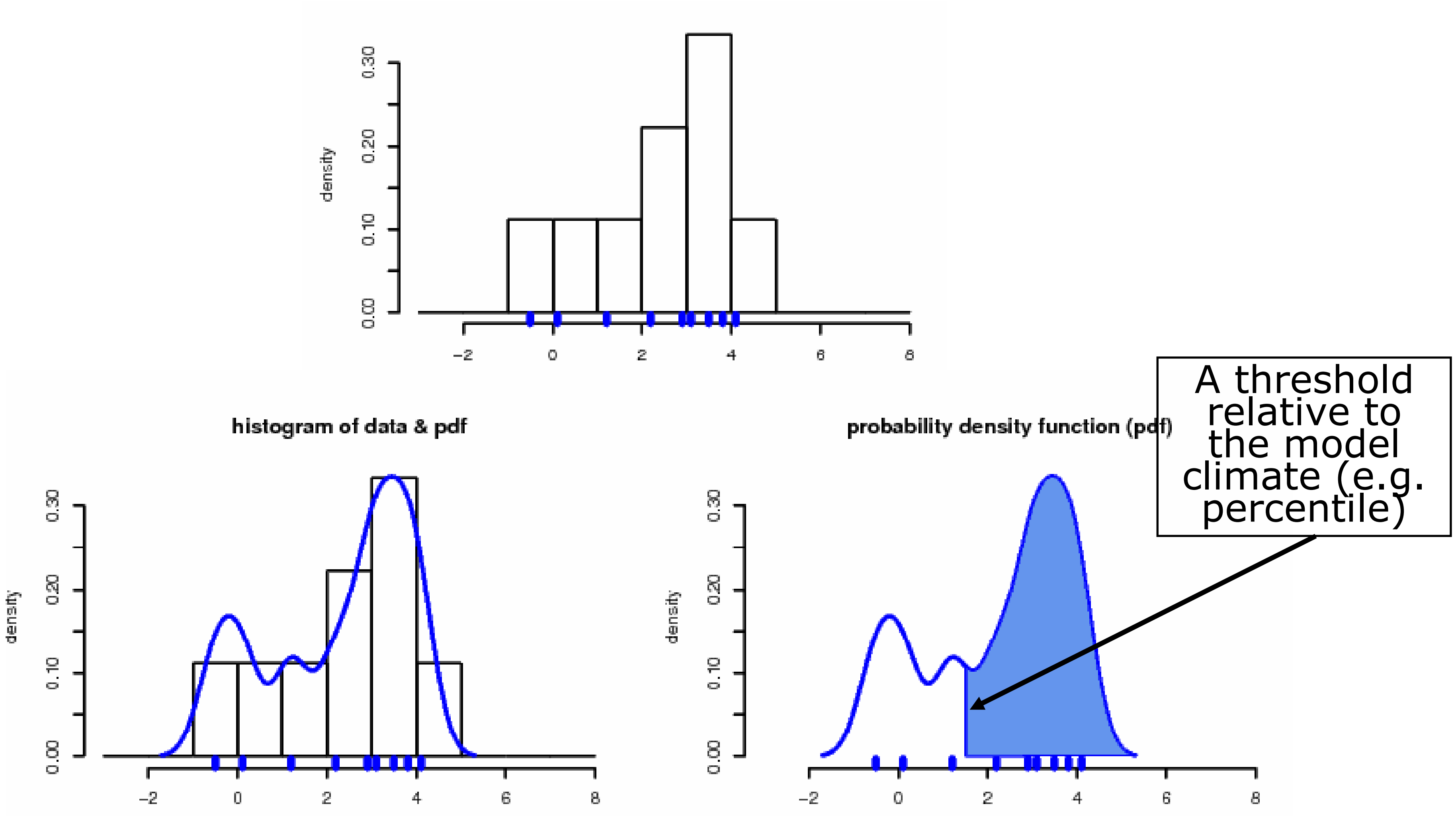
Seasonal re-forecasts for Europe

System 3 precipitation re-forecasts for Southern (left) and Northern Europe (right) over 1981-2005. The green box-and-whisker show the ensemble range, the blue dot the ensemble mean and the red dot the GPCP value.



From ensembles to probability forecasts

Constructing a probability forecast from a nine-member ensemble



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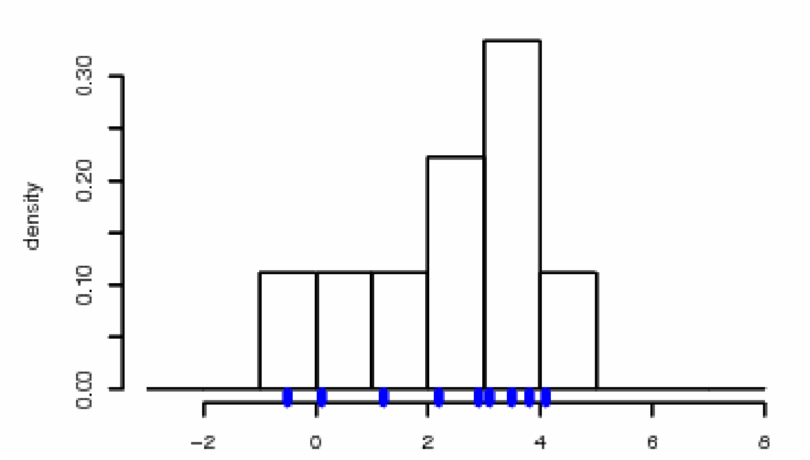
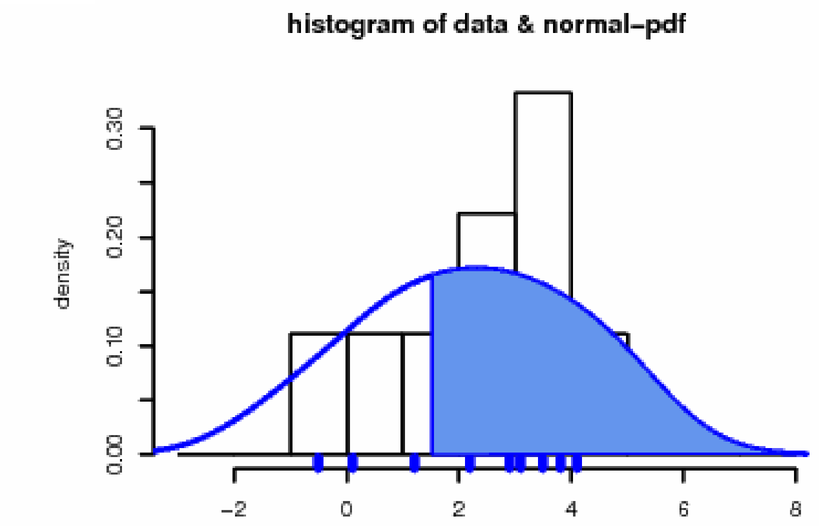
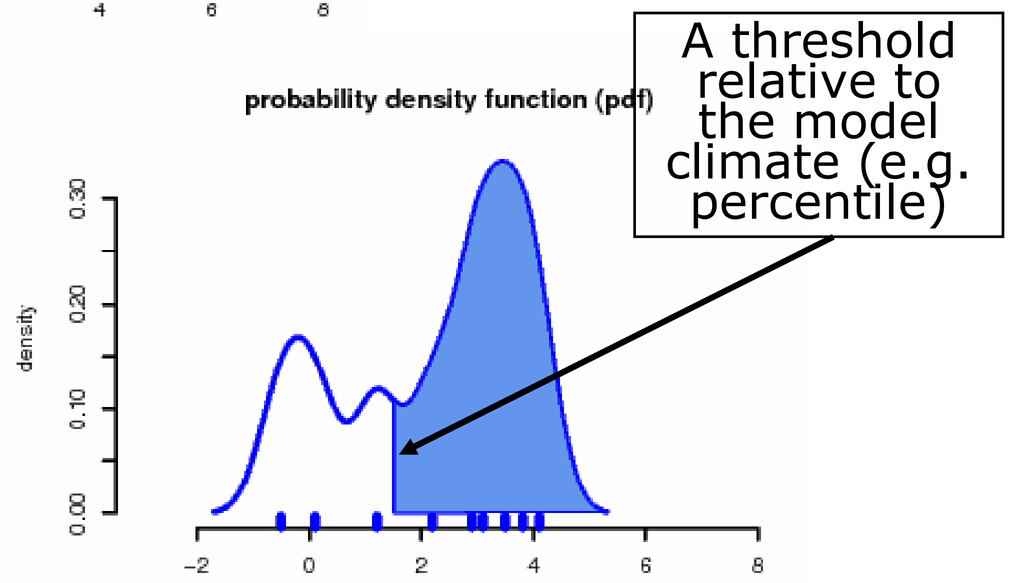
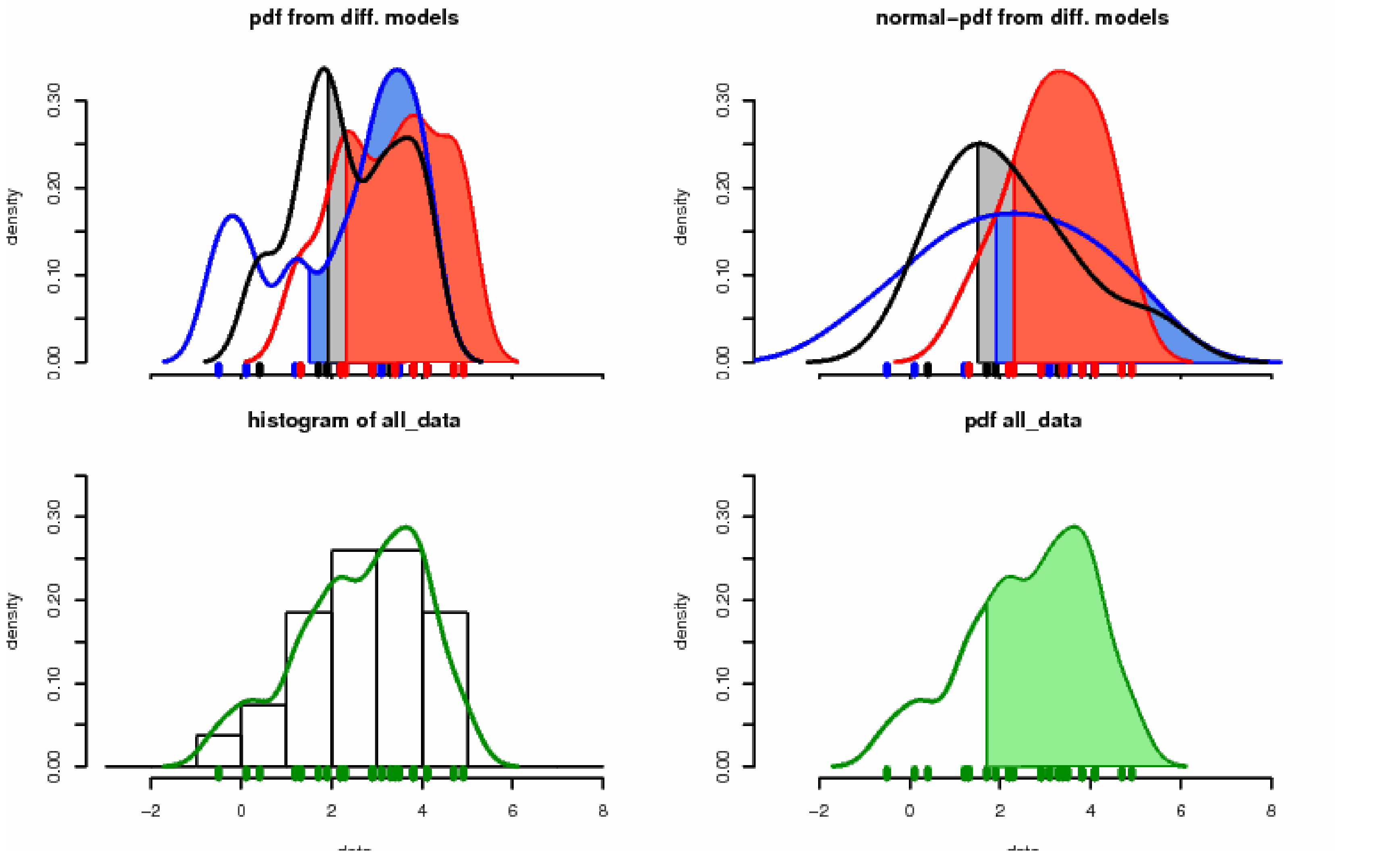






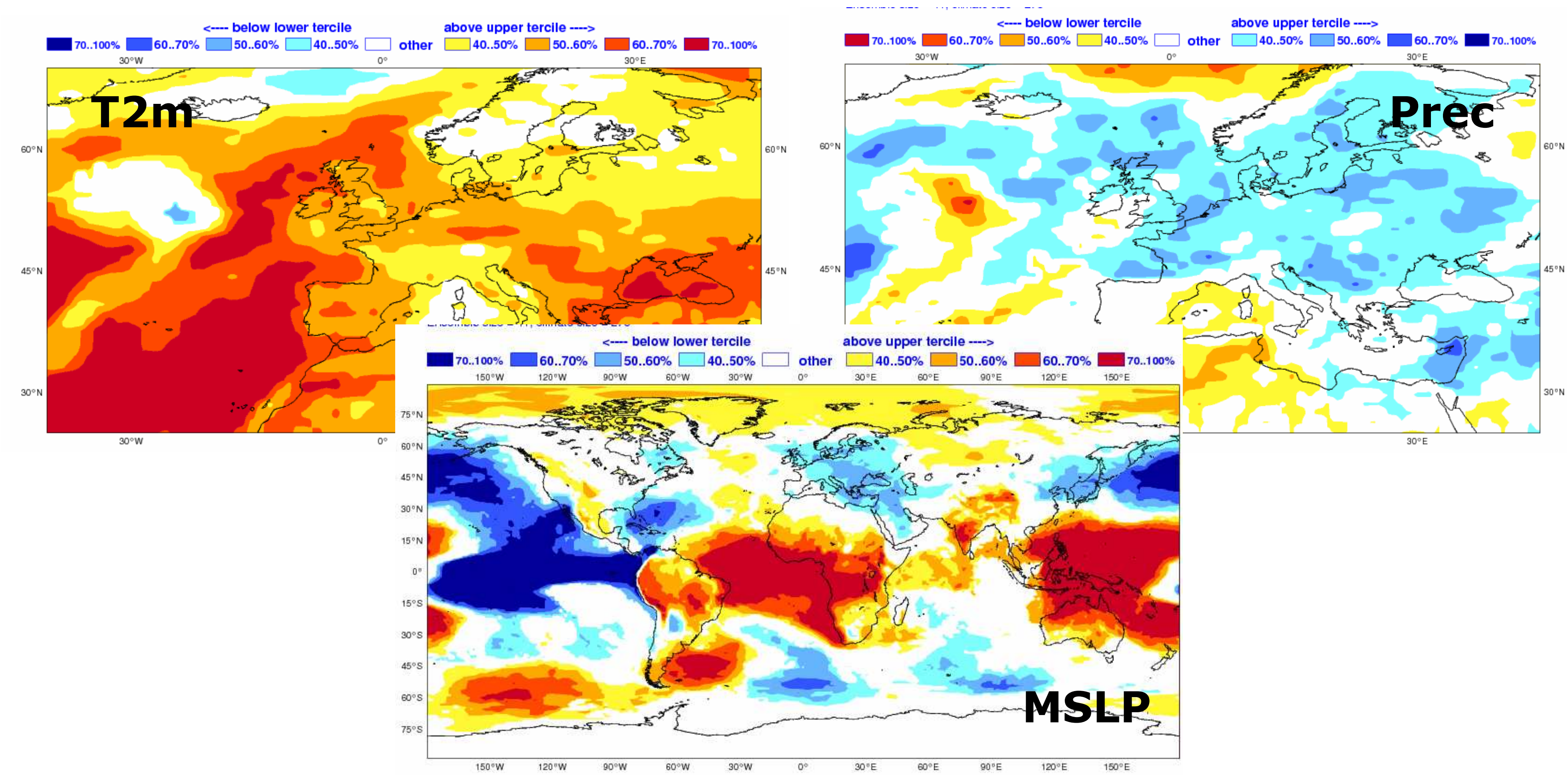
From ensembles to probability forecasts

Constructing a probability forecast from a multi-model ensemble



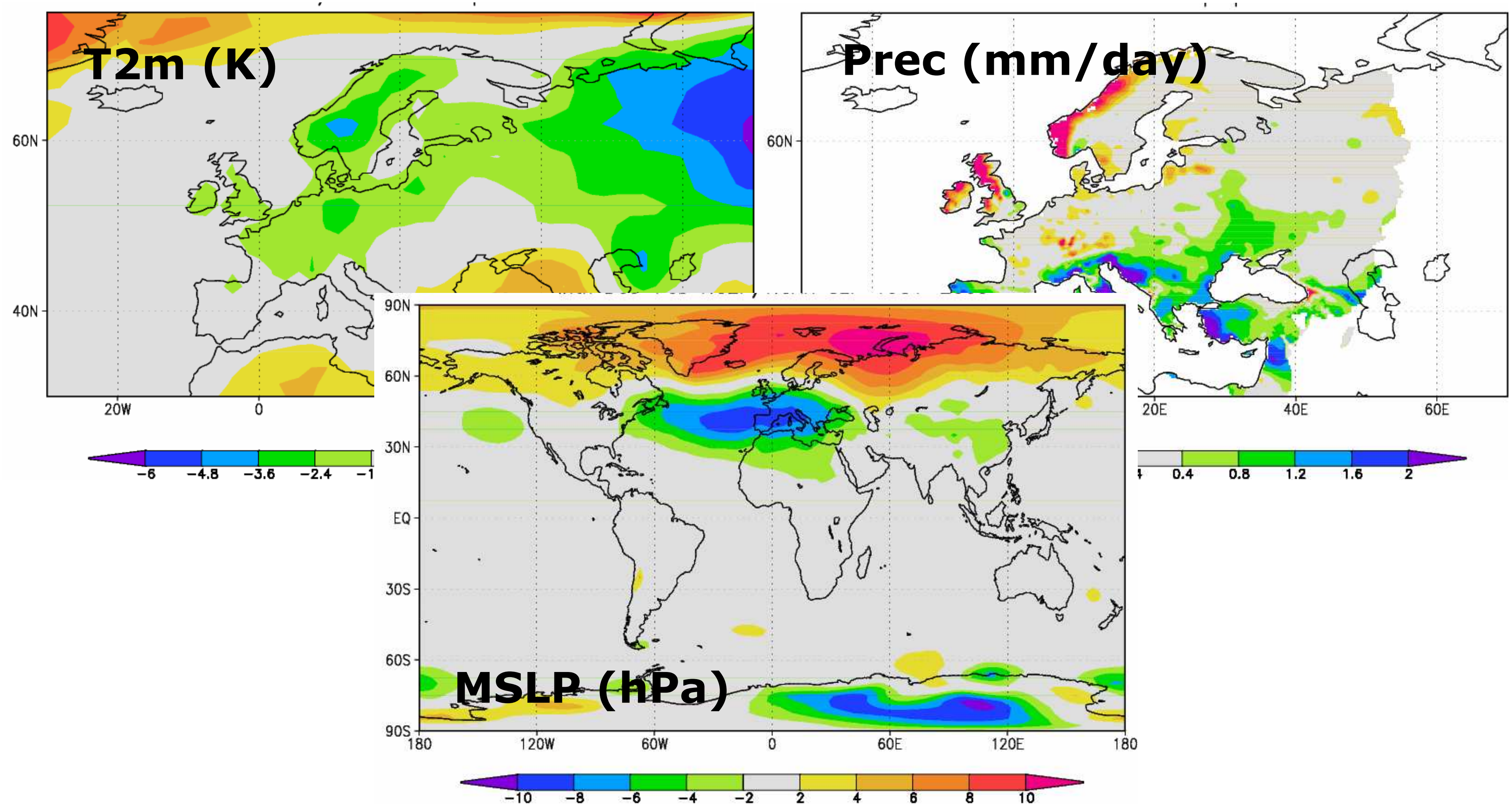
Probabilistic prediction

One-month lead DJF 2009-10 System 3 seasonal forecasts: tercile summary



References: what actually happened

DJF 2009-10 seasonal anomalies wrt 1981-2005.



Probabilistic prediction

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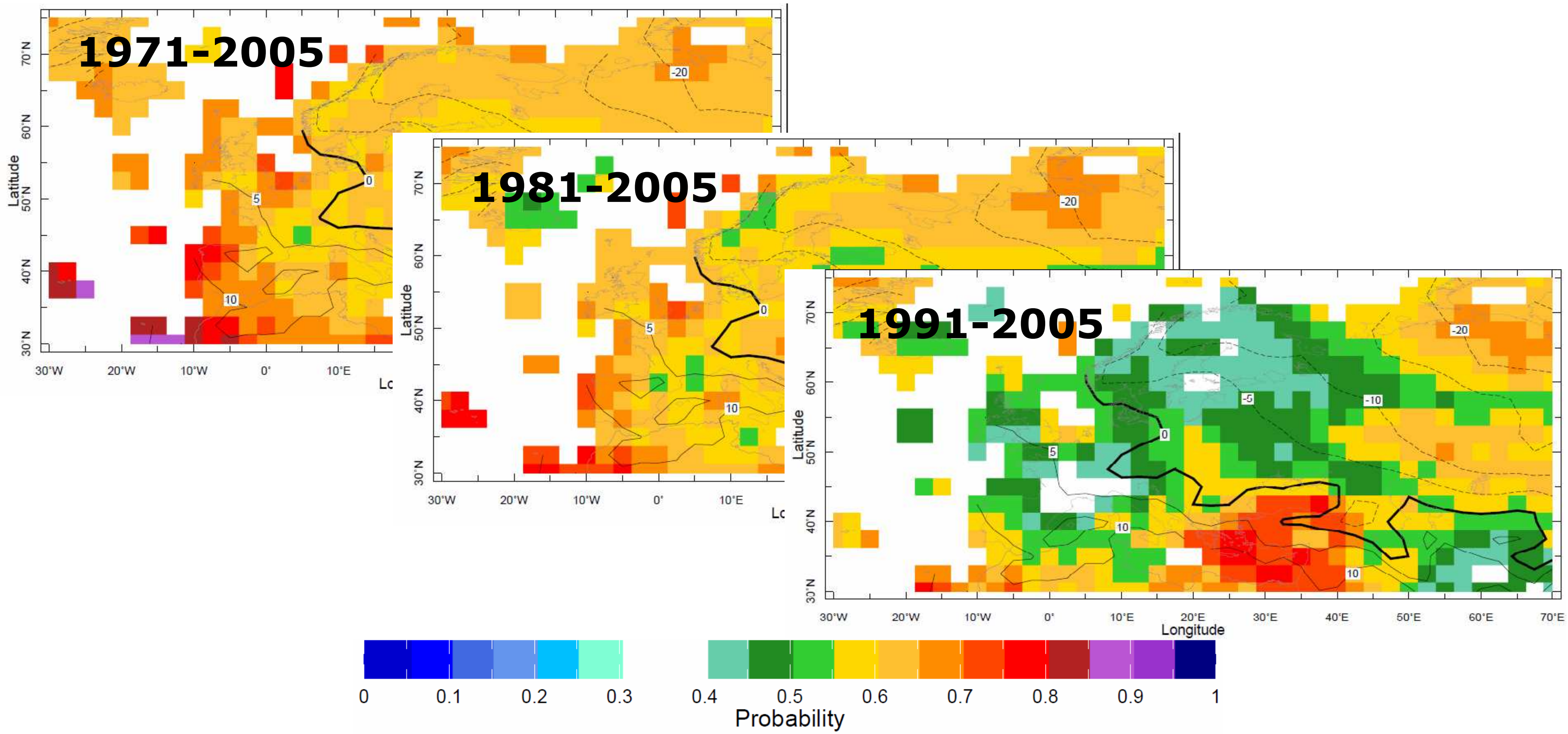
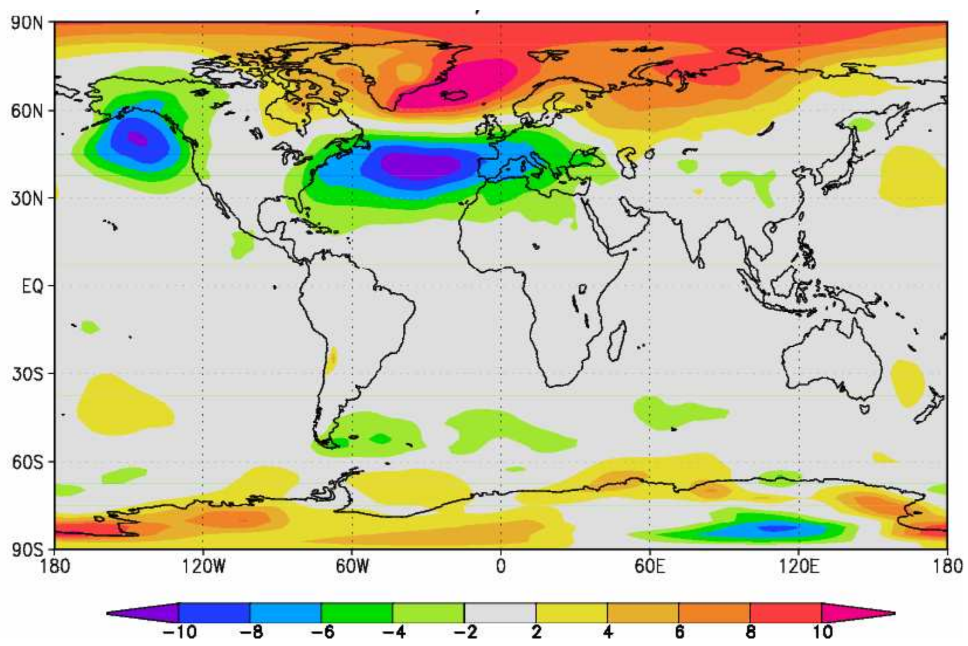
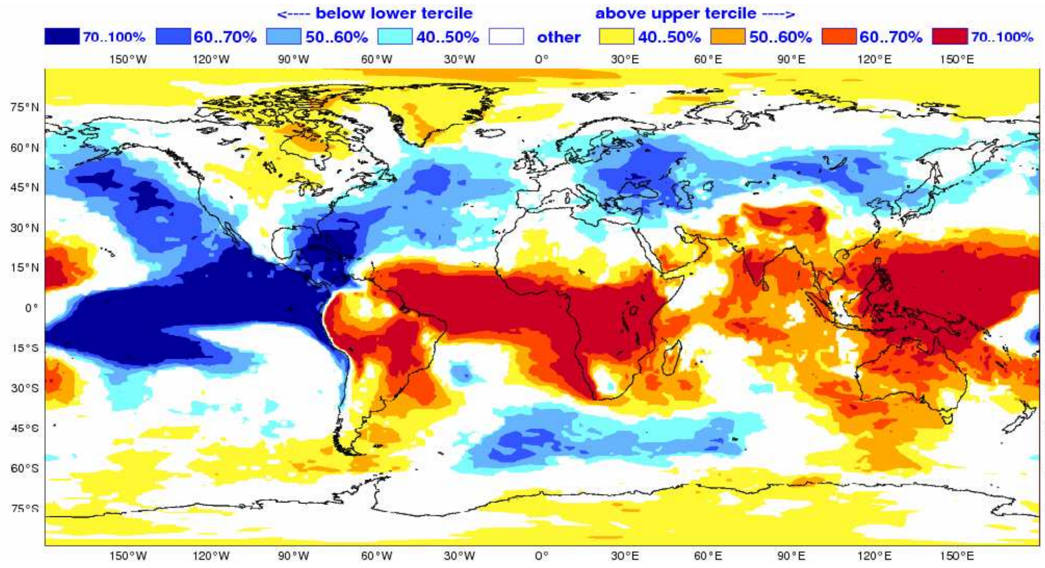
One-month lead DJF 2009-10 IRI (flexible format) temperature forecasts for anom. above the upper tercile



December start date forecasts: JFM

JFM 2010 mean sea level pressure seasonal anomalies for (left) NCEP/NCAR R1 (hPa) and (right) tercile summary for the one-month lead System 3 forecasts wrt 1981-2005.





Temperature skill: System 3

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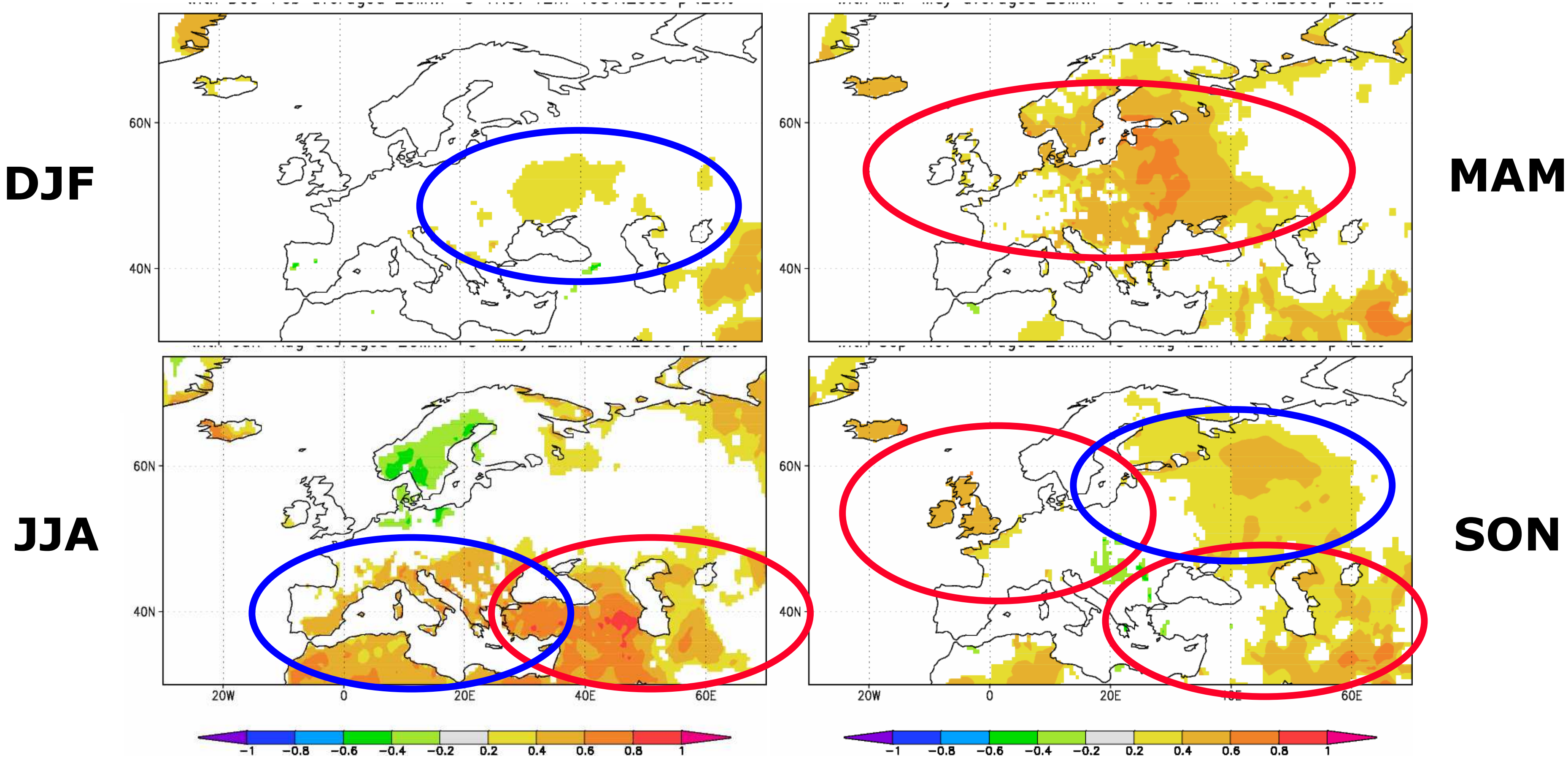
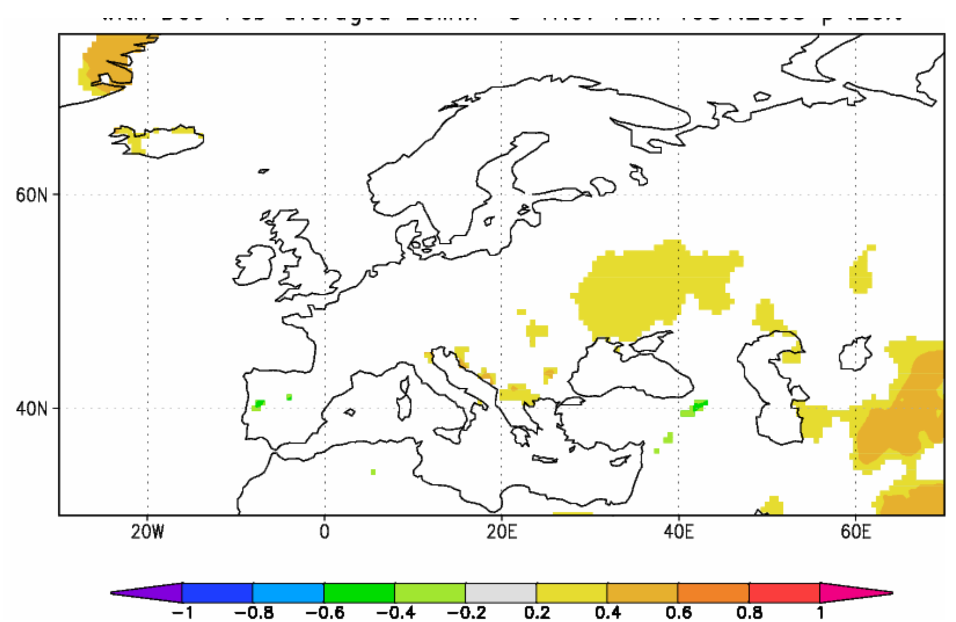
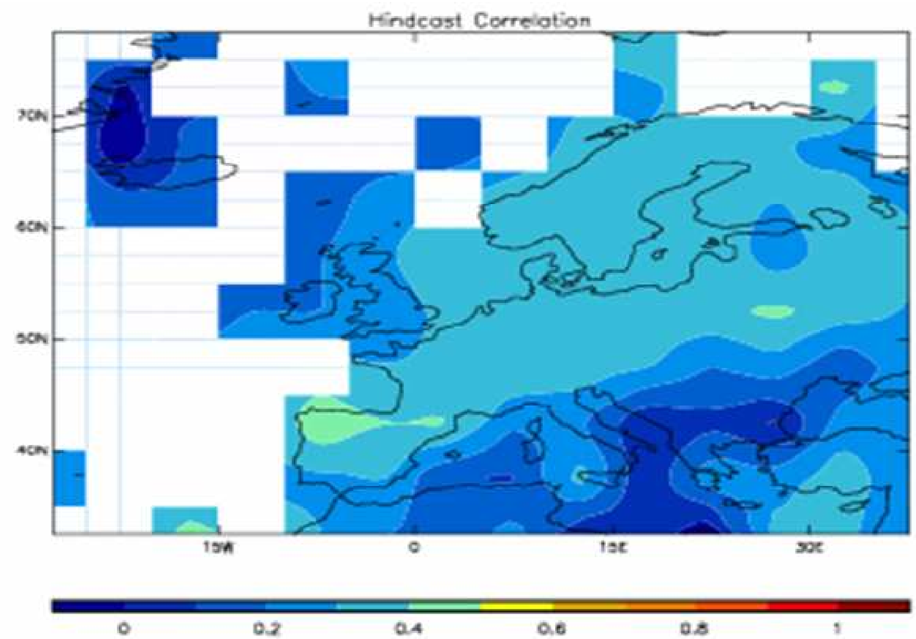
Correlation of System 3 seasonal forecasts of temperature wrt GHCN over 1981-2005. Only values statistically significant with 80% confidence are plotted.



Temperature skill: Potential predictability

(Left) Correlation of System 3 DJF seasonal forecasts of temperature wrt GHCN over 1981-2005. (Right) Potential predictability of DJF seasonal predictions using Folland et al. (2010) statistical model.





Precipitation skill: System 3

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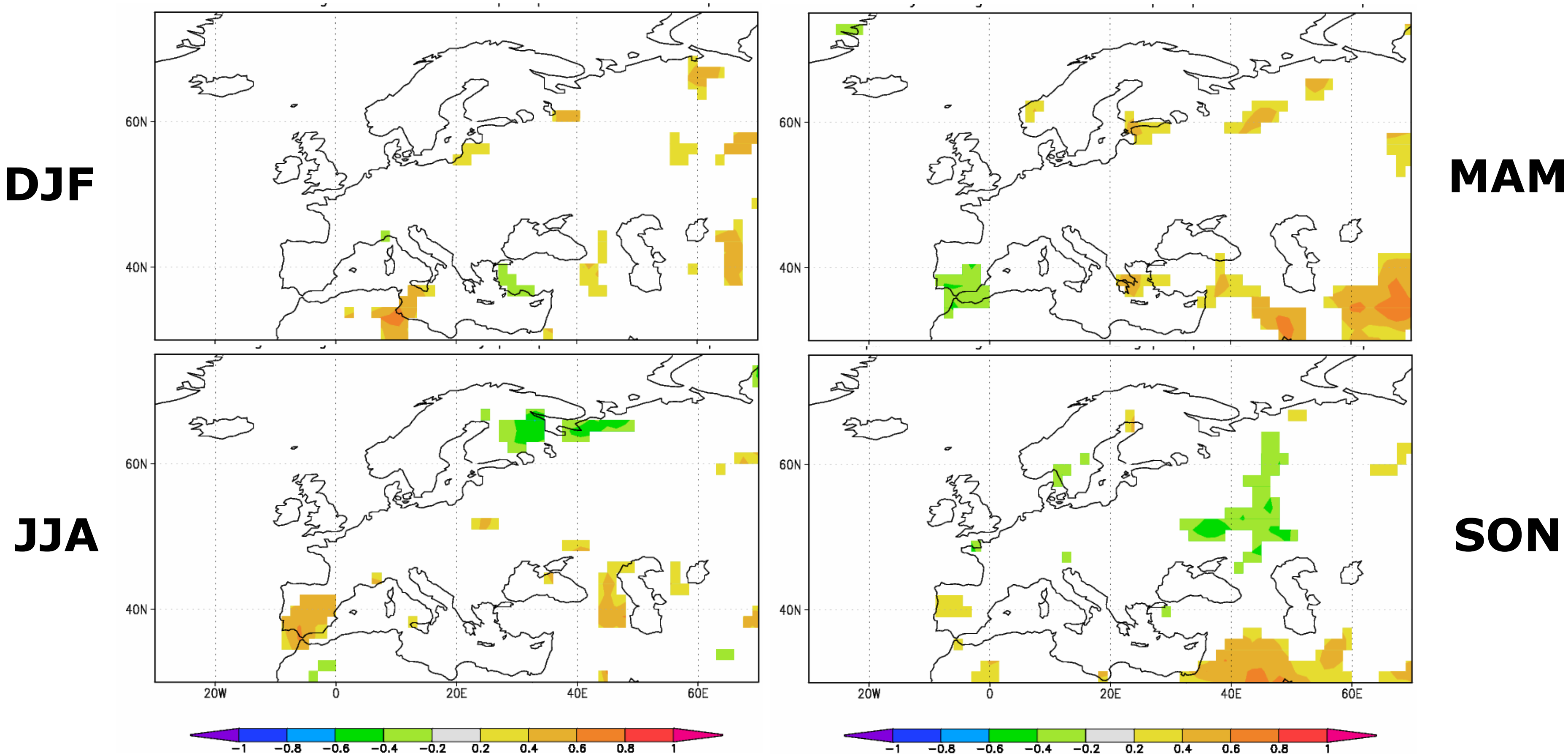
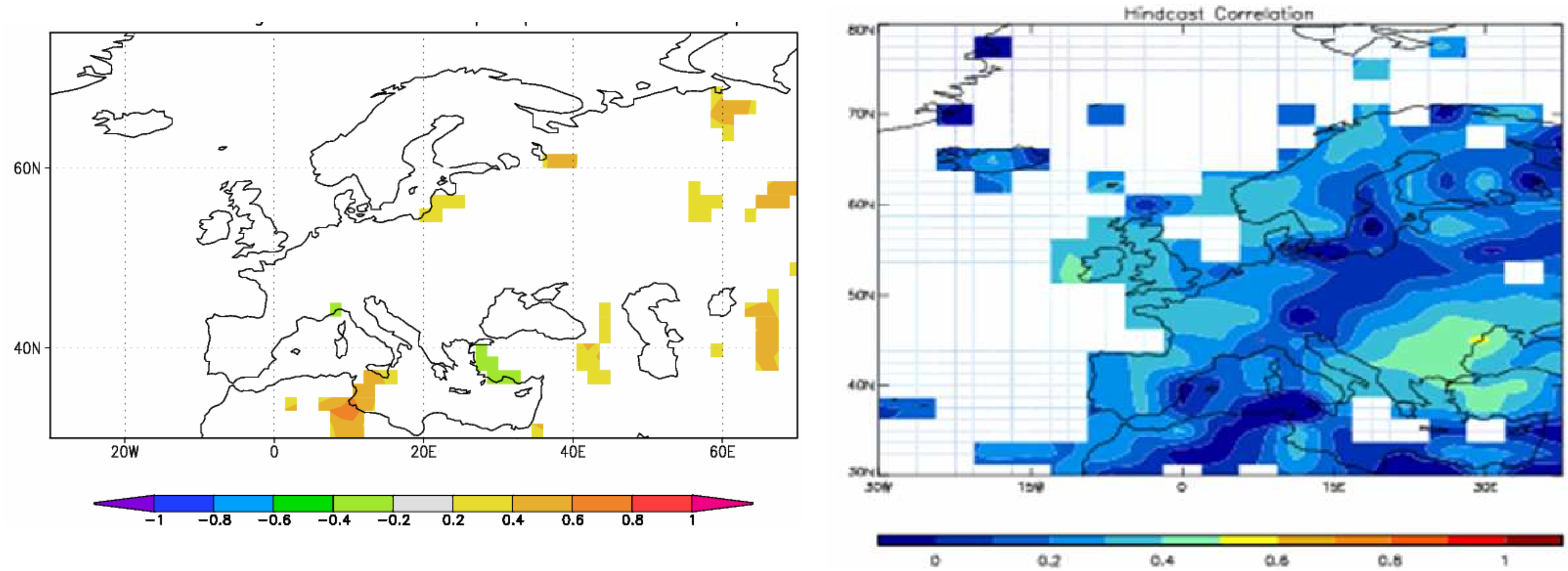
Correlation of System 3 seasonal forecasts of precipitation wrt GPCC over 1981-2005. Only values statistically significant with 80% confidence are plotted.



Precipitation skill: System 3

(Left) Correlation of System 3 DJF seasonal forecasts of precipitation wrt GPCC over 1981-2005. (Right) Potential predictability of DJF seasonal predictions using Folland et al. (2010) statistical model.



Sources of predictability and error

- ENSO and tropical Atlantic
- Extratropical SSTs
- Trends and anthropogenic warming
- Model inadequacy
- Model improvement
- Soil moisture
- Snow
- Stratospheric processes
- Volcanic aerosol

Global skill: System 3

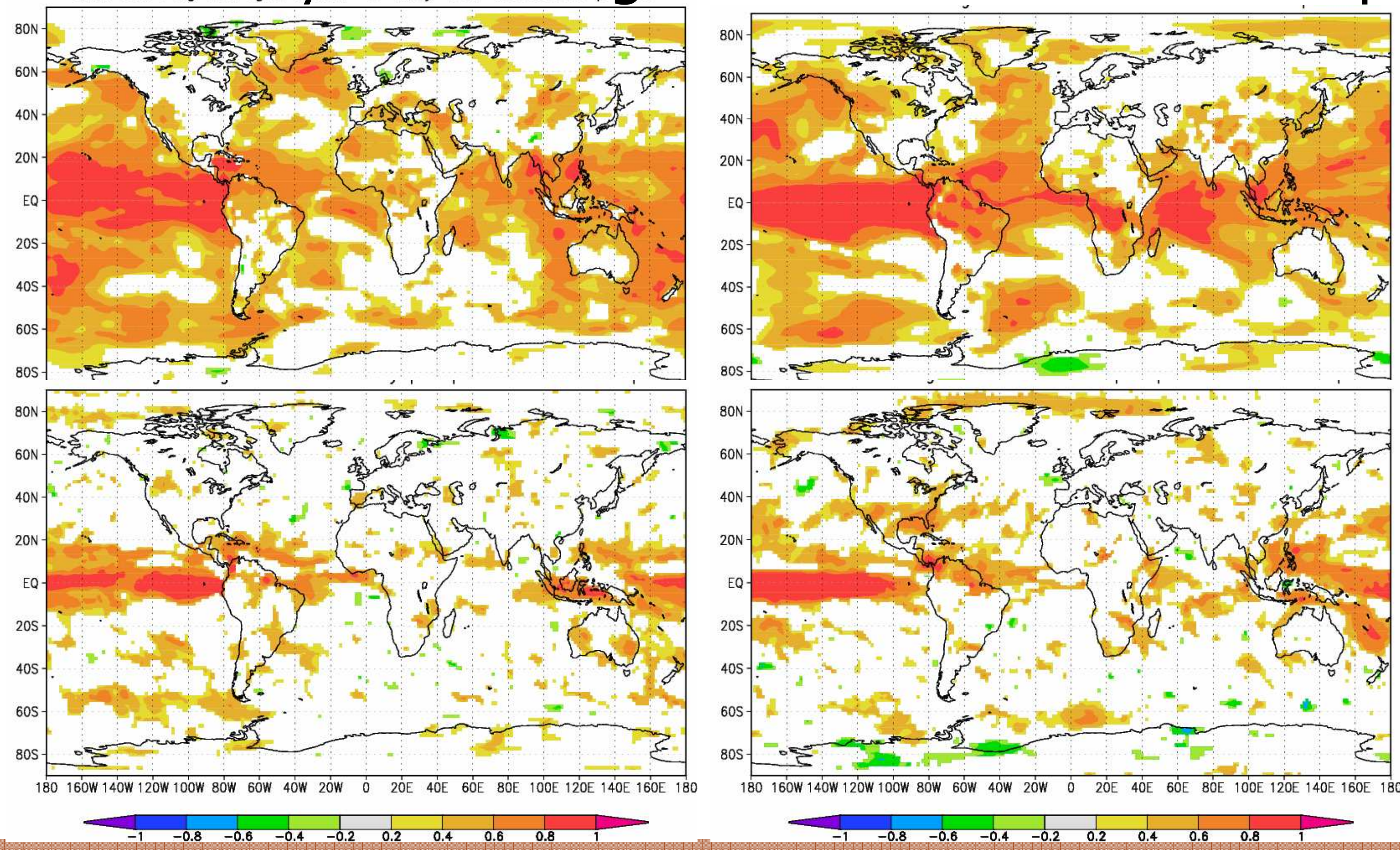
Correlation of System 3 seasonal forecasts of temperature (top) and precipitation (bottom) wrt GHCN and GPCC over 1981-2005. Only values significant with 80% conf. plotted.

JJA T2m

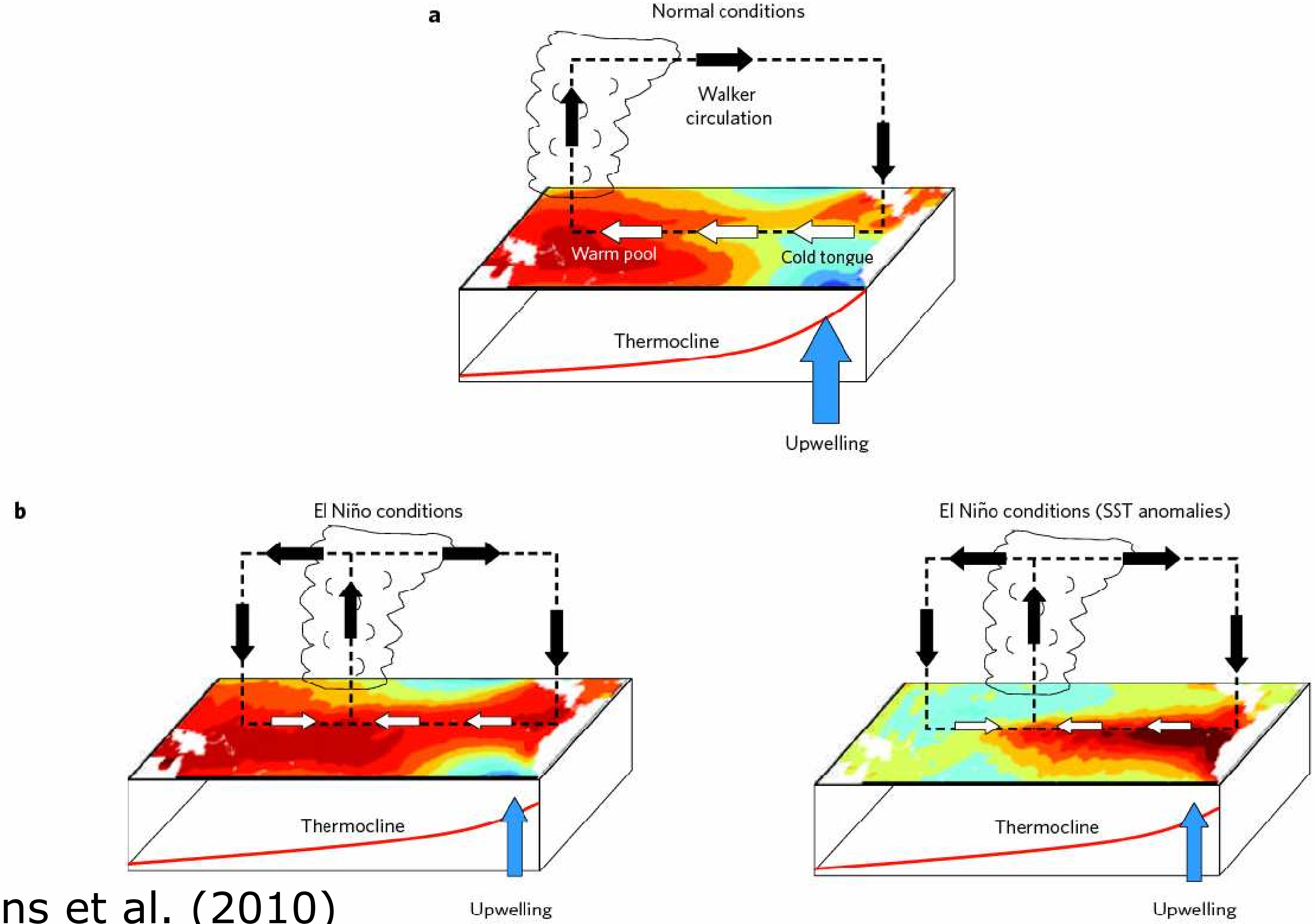
DJF T2m

JJA Prec

DJF Prec



Sources of predictability: ENSO



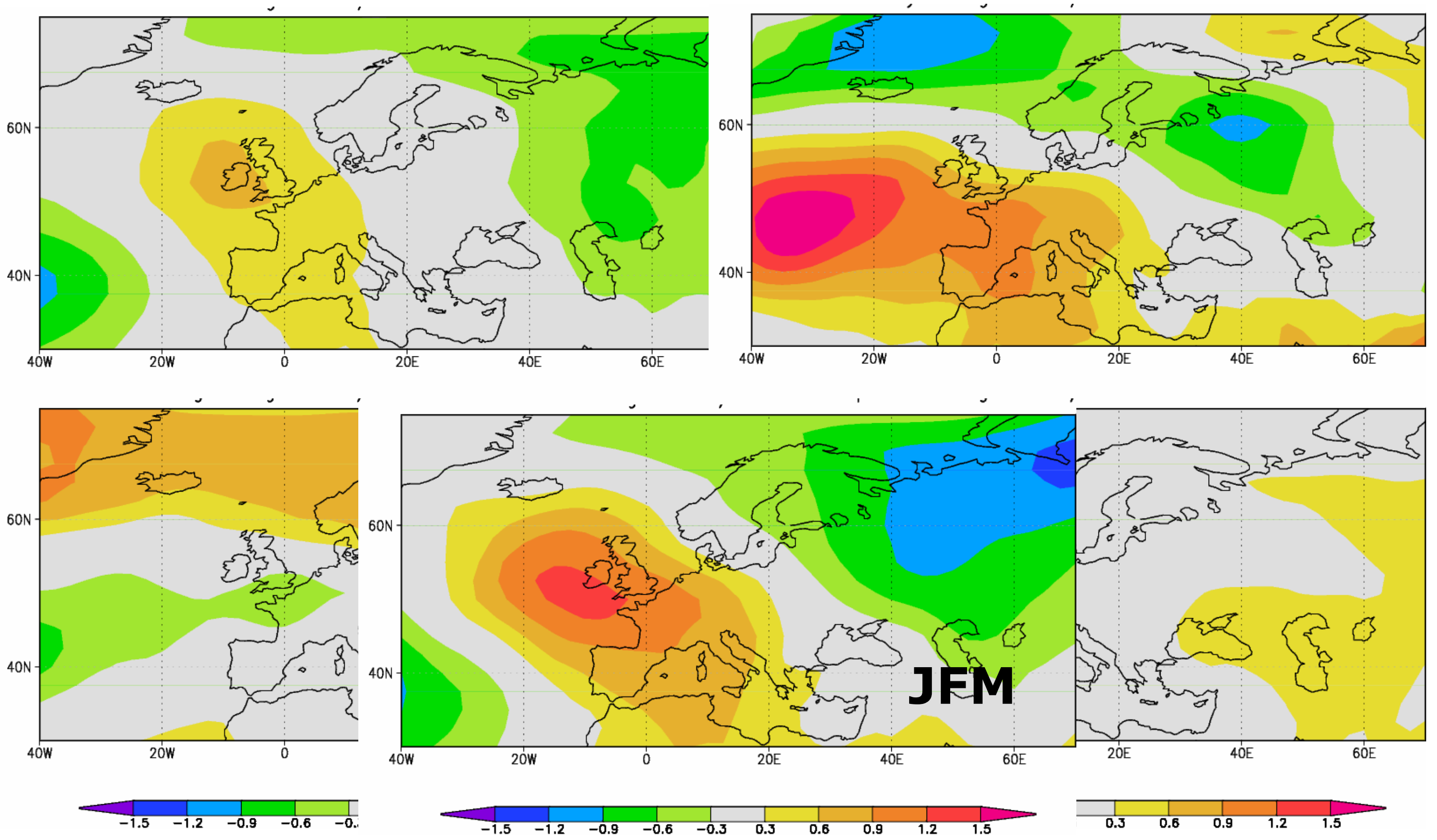
Collins et al. (2010)

ENSO teleconnections: observations

Regression of NCEP/NCAR R1 mean sea level pressure on HadISST1 Niño3.4 time series (hPa/K) over 1981-2005.

DJF **MAM**

JJA **SON**



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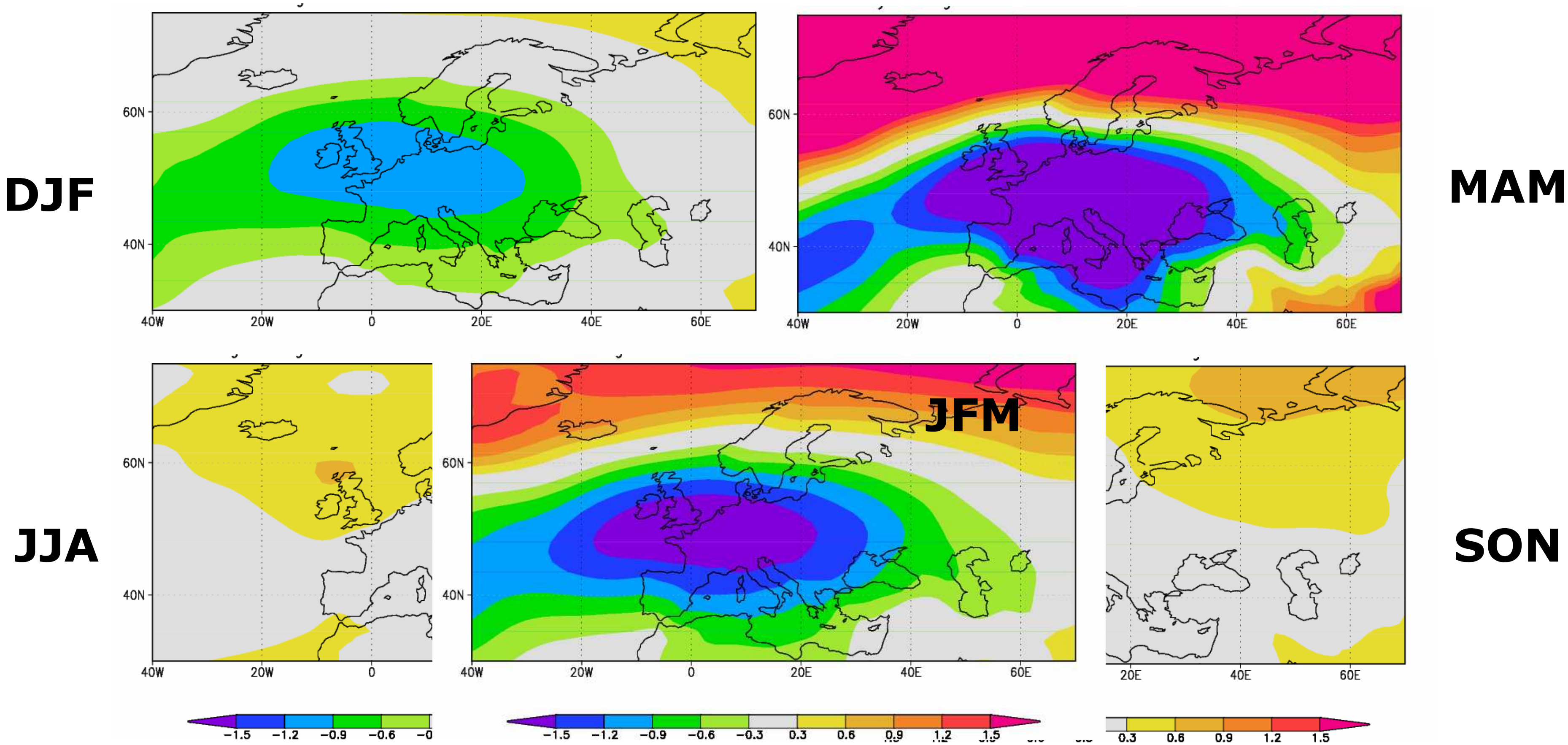
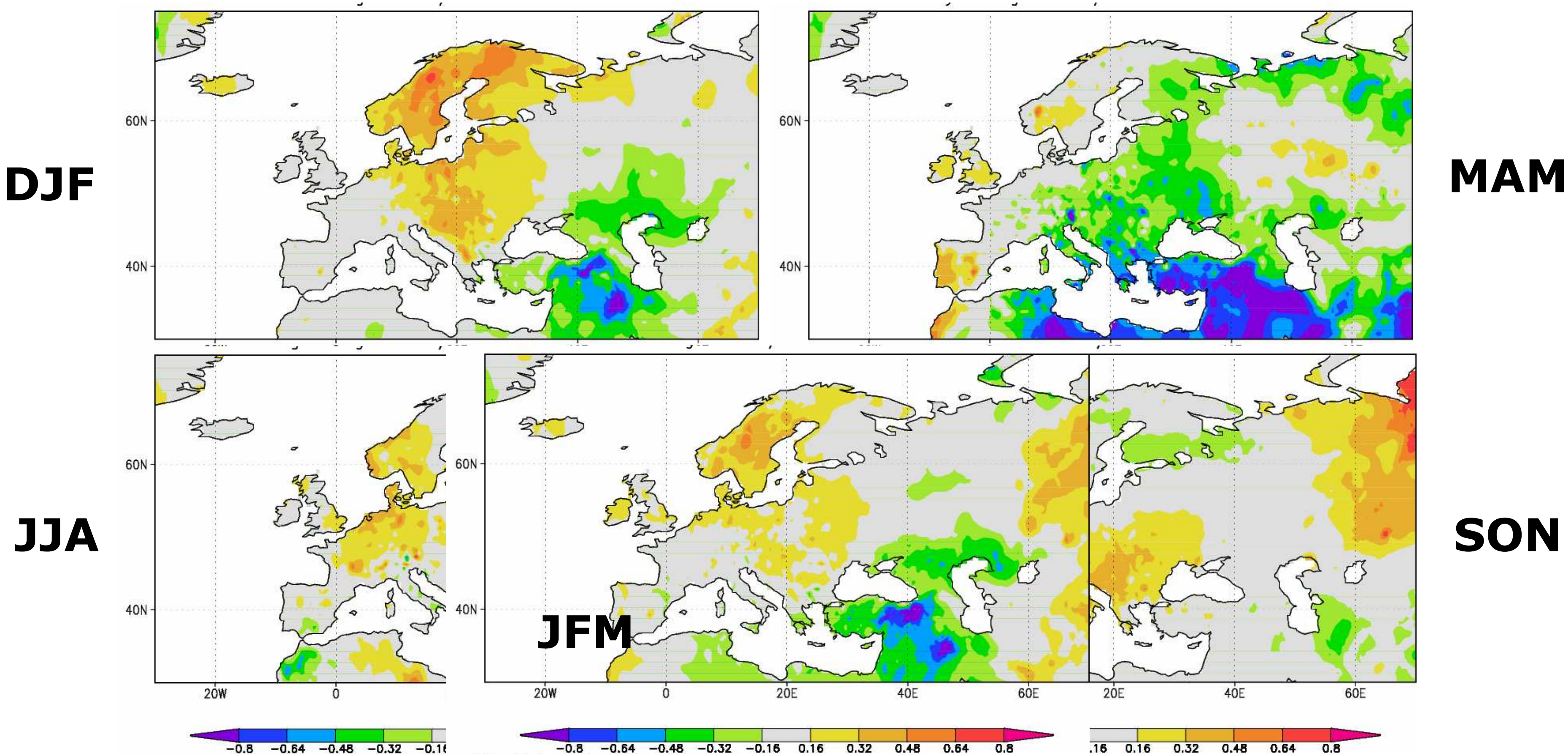
ENSO teleconnections: System 3

Regression of System 3 seasonal temperature on predicted Niño3.4 SST time series (hPa/K) over 1981-2005.



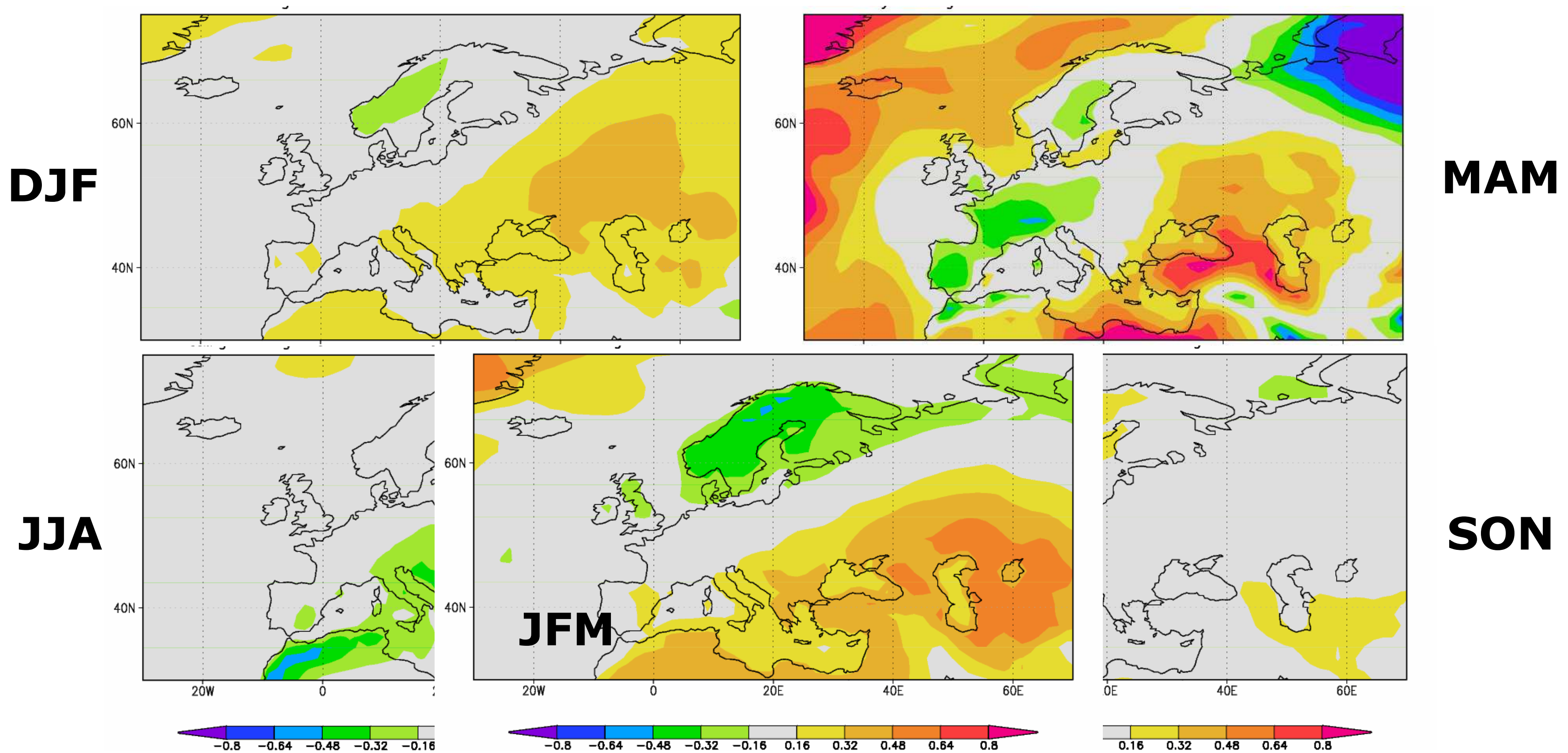
ENSO teleconnections: observations

Regression of GHCN seasonal temperature on HadISST1 Niño3.4 time series (K/K) over 1981-2005.



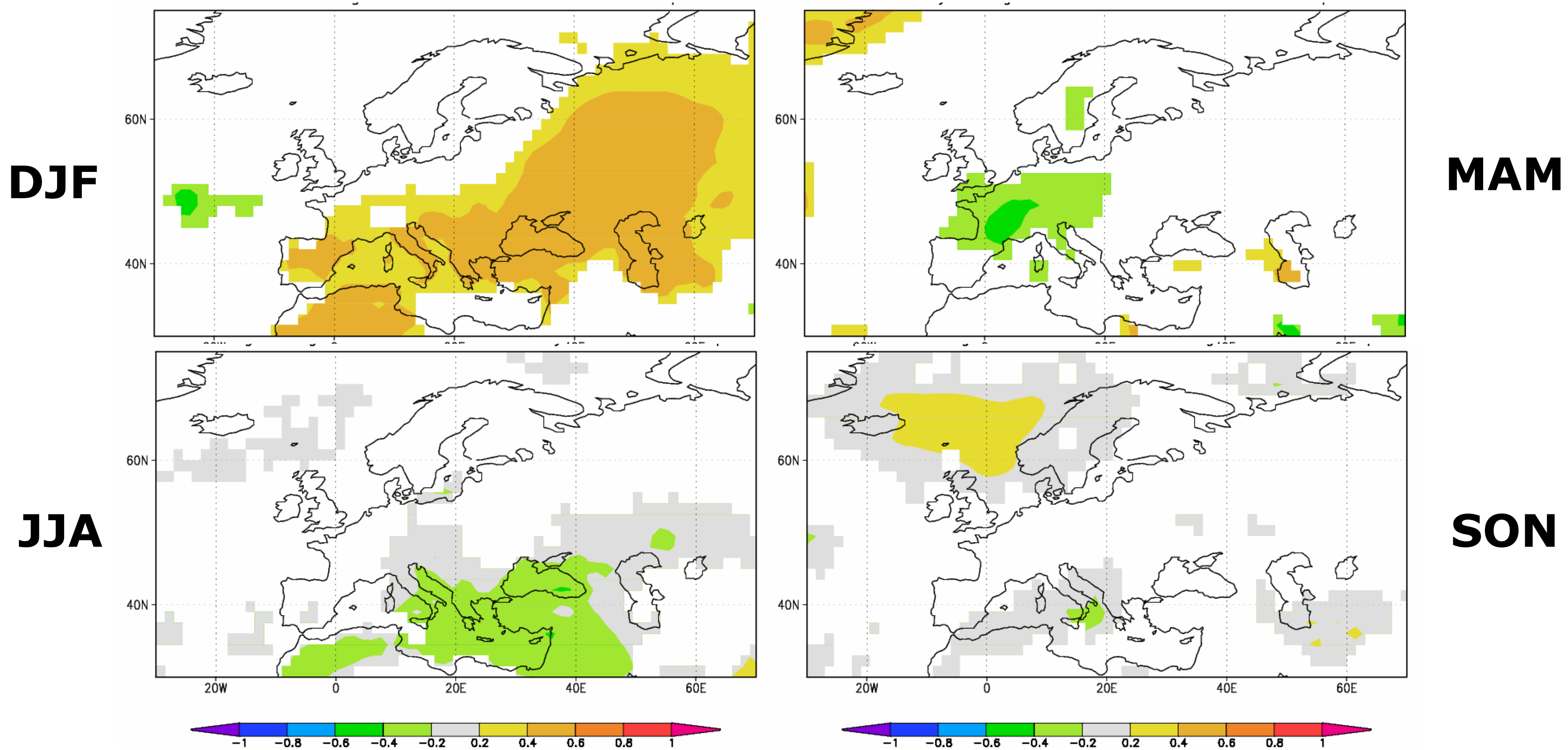
ENSO teleconnections: System 3

Regression of System 3 seasonal temperature on predicted Niño3.4 SST time series (K/K) over 1981-2005.



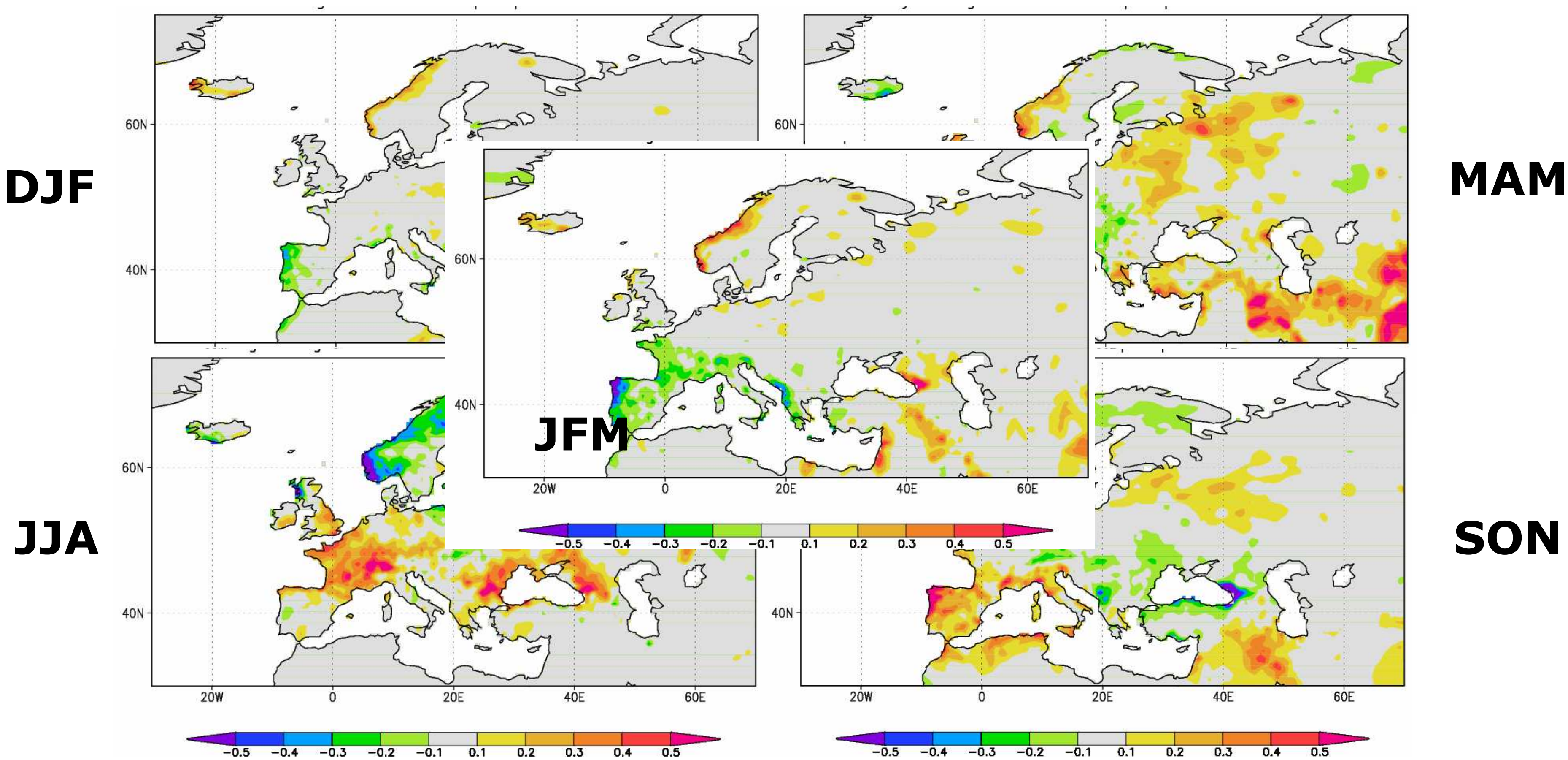
ENSO teleconnections: System 3

Correlation of System 3 seasonal temperature with HadISST Niño3.4 time series over 1981-2005. Only values statistically significant with 80% confidence are plotted.



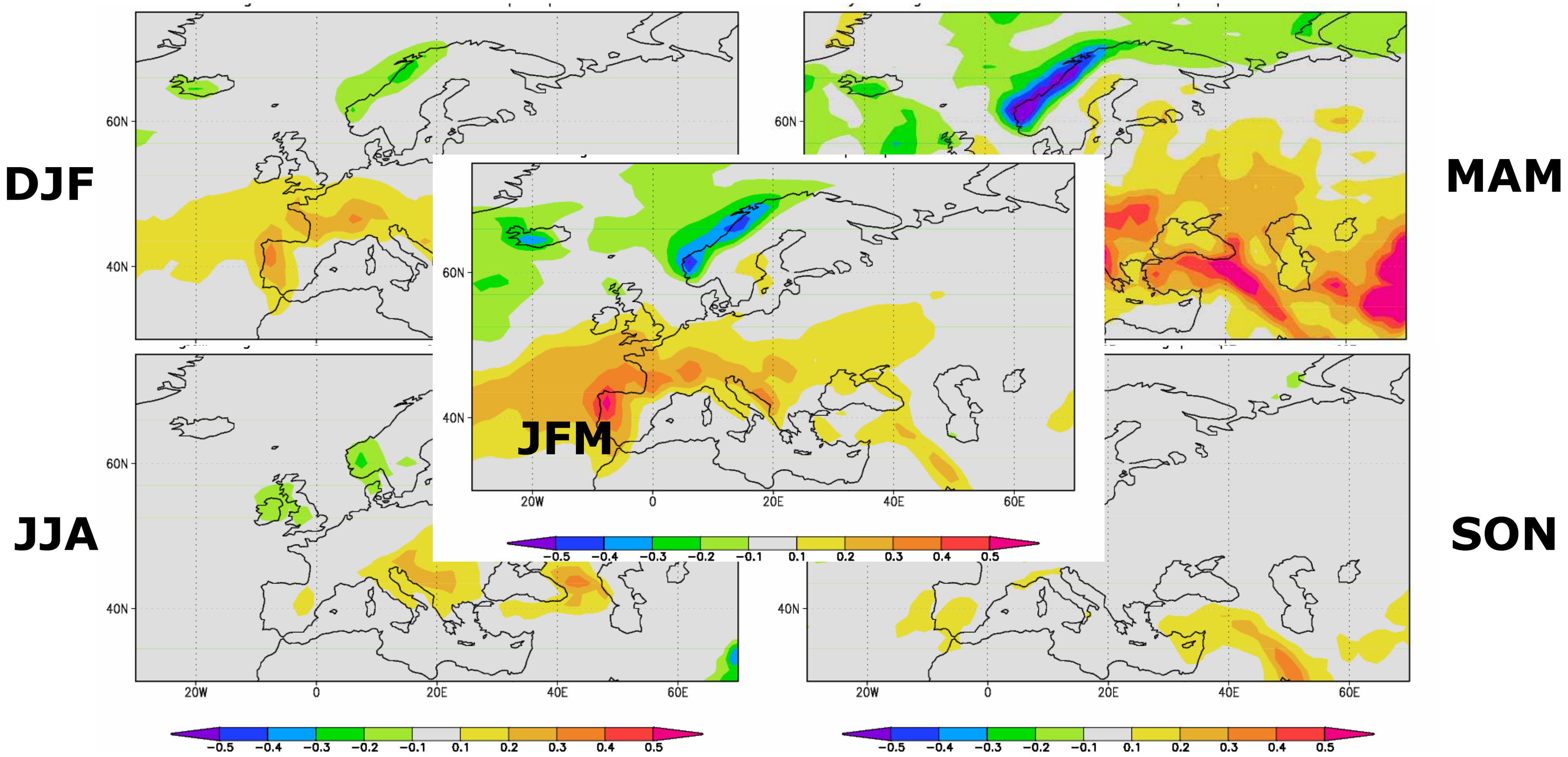
ENSO teleconnections: observations

Regression of GPCC seasonal precipitation on HadISST1 Niño3.4 time series (mm/day/K) over 1981-2005.



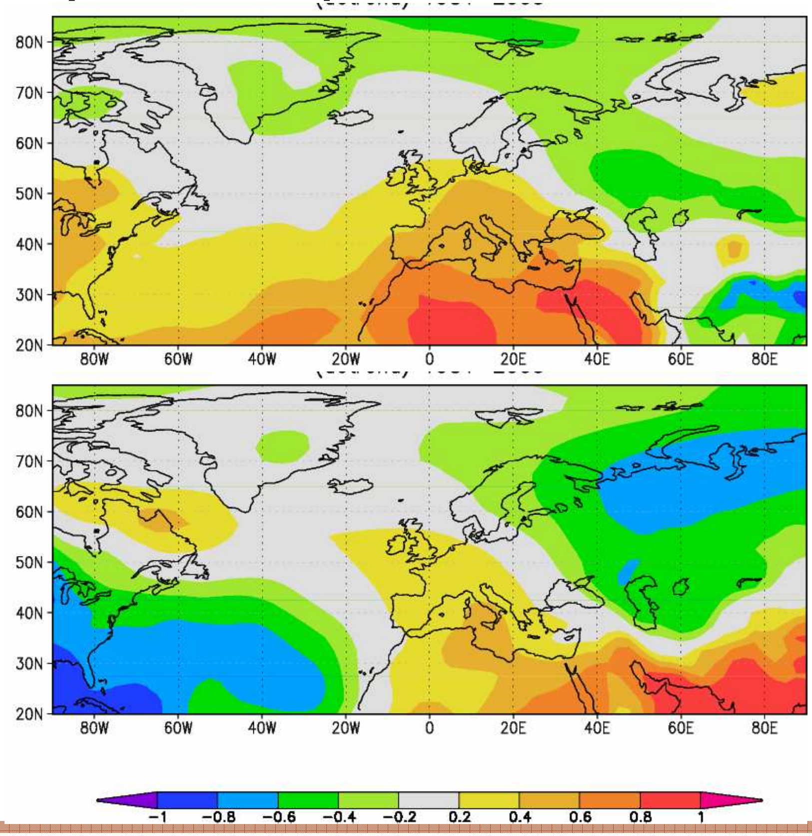
ENSO teleconnections: System 3

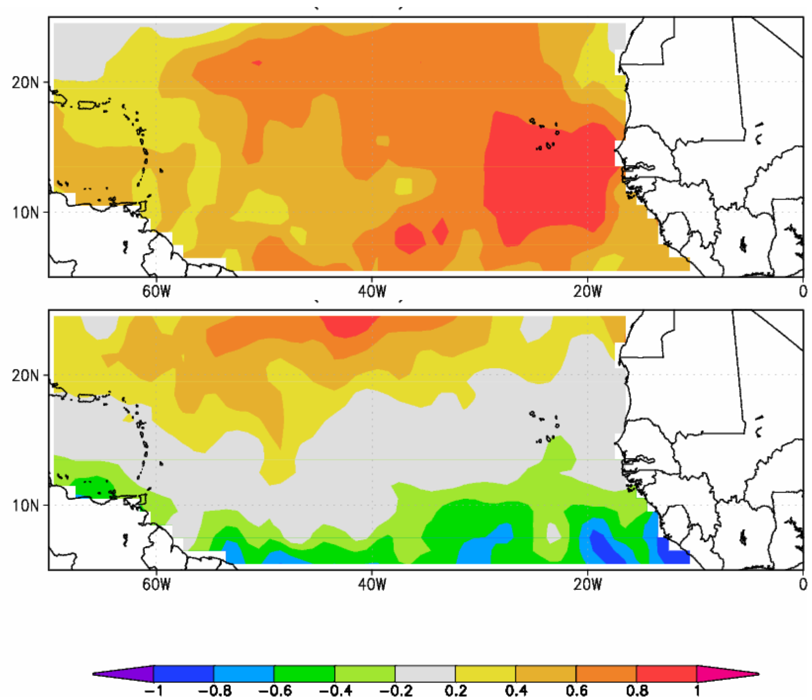
Regression of System 3 seasonal precipitation on predicted Niño3.4 SST time series (mm/day/K) over 1981-2005.



Tropical SSTs: the Atlantic case

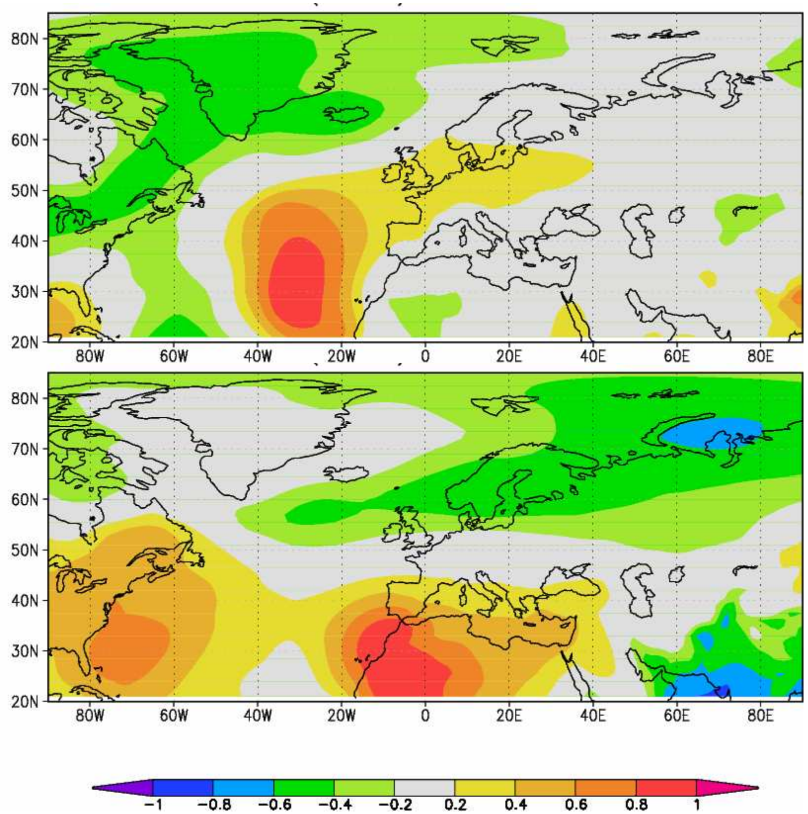
Leading two pairs of the MCA between NCEP/NCAR R1 DJF mean sea level pressure (left) and the leading October North Atlantic HadISST1 SSTs (right) over 1981-2005. The two pairs explain 31% and 16% of the covariance.

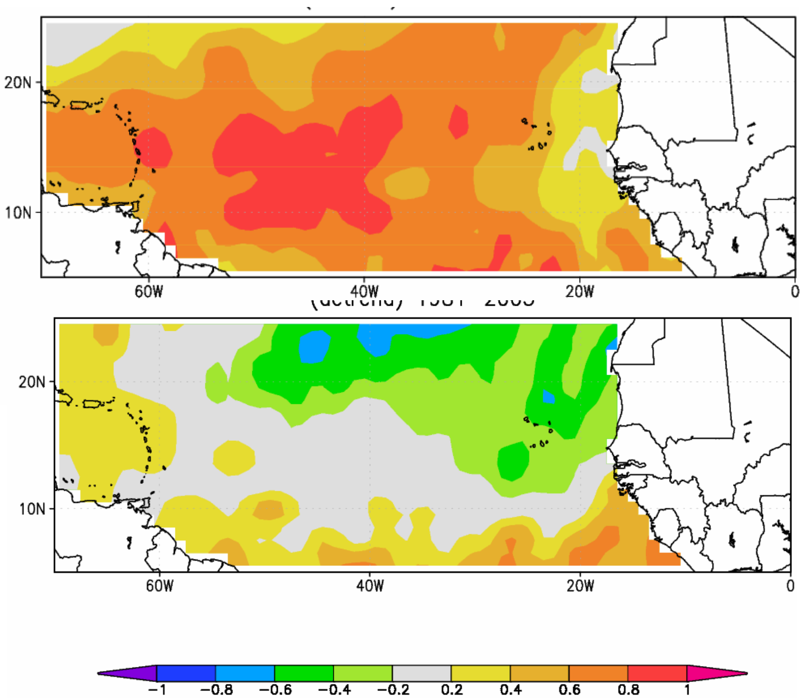




Tropical SSTs: the Atlantic case

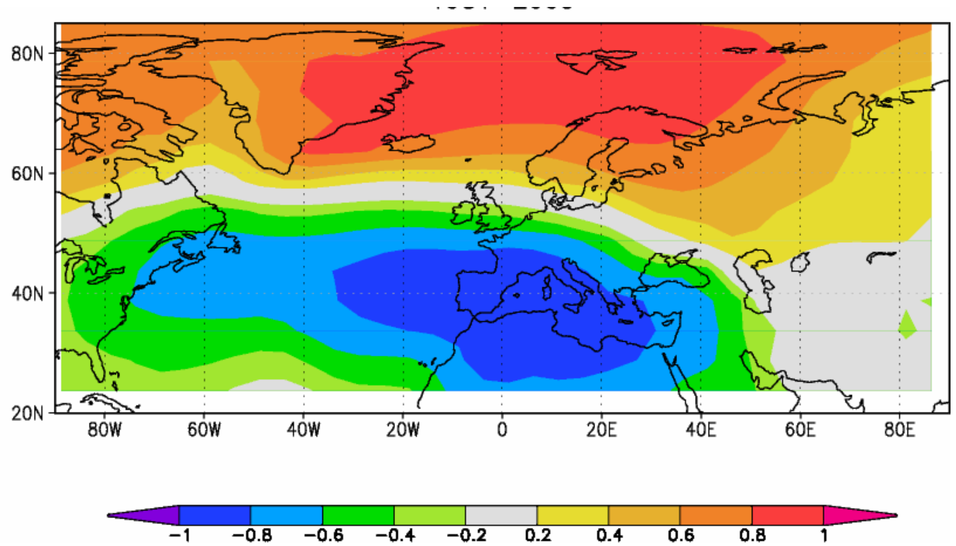
Leading two pairs of the MCA between System 3 one-month lead DJF MSLP (left) and the leading October North Atlantic HadISST1 SSTs (right) over 1981-2005. The two pairs explain 24% and 17% of the covariance.

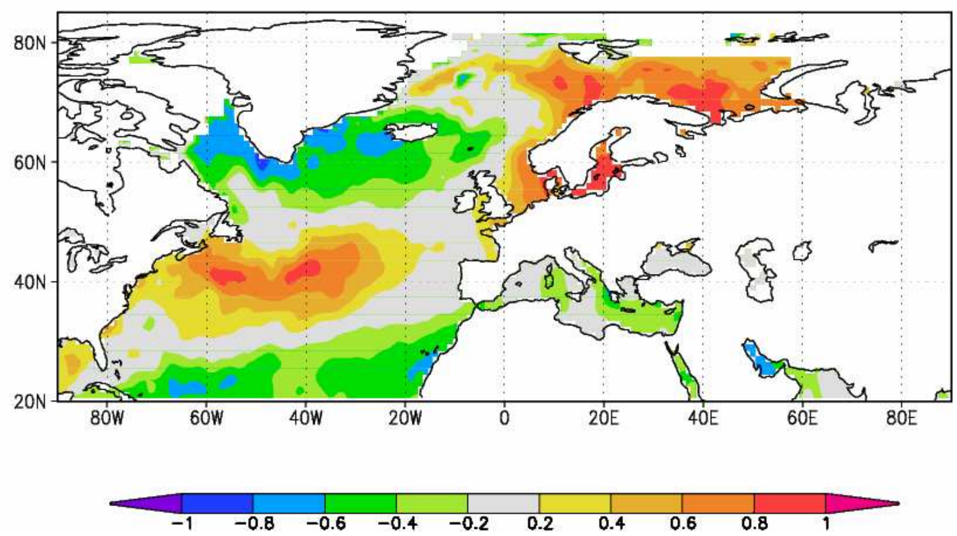




Extratropical SSTs: the North Atlantic

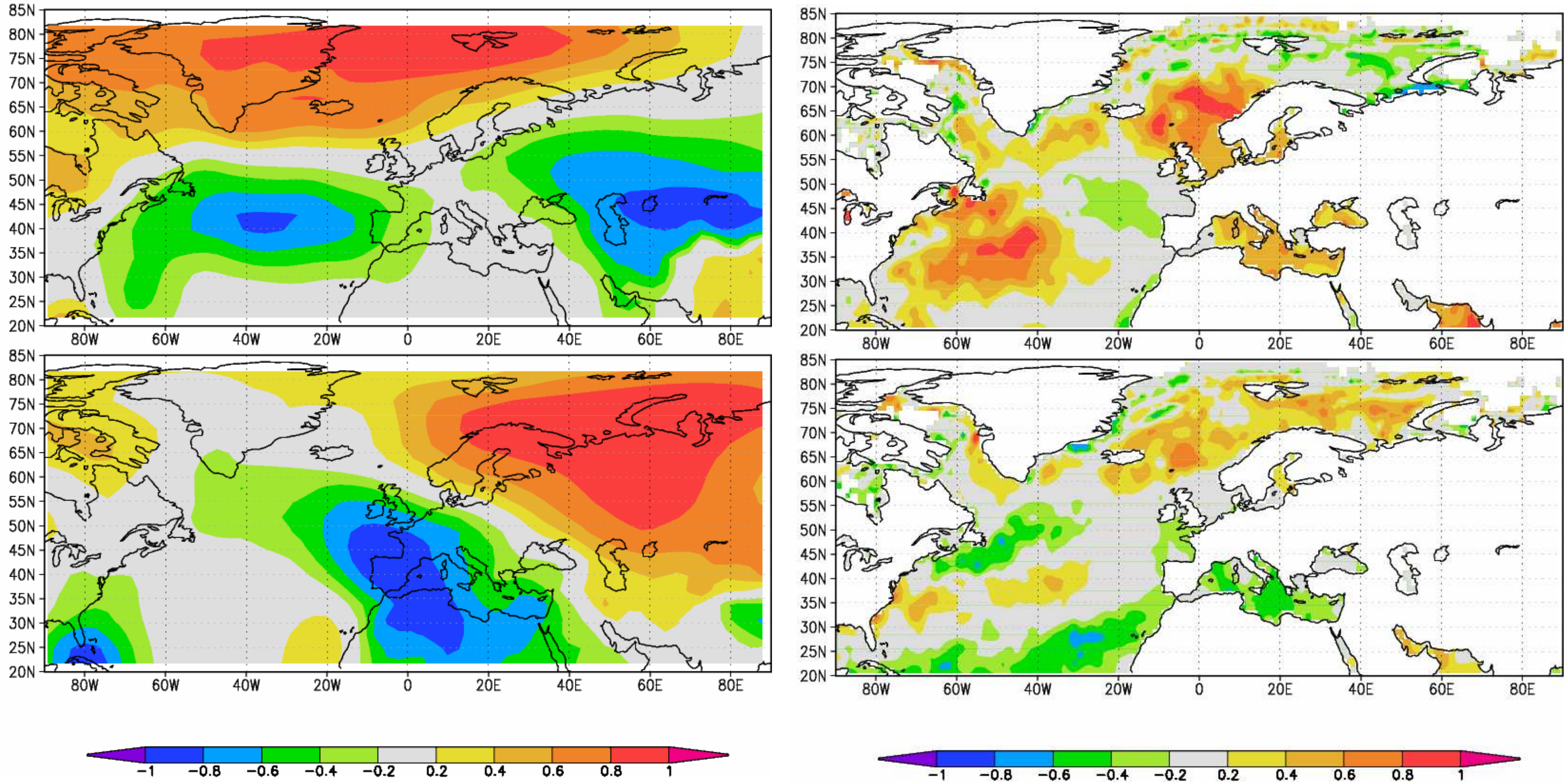
Leading pair of the MCA between NCEP/NCAR R1 DJF mean sea level pressure (left) and the leading May North Atlantic HadISST1 SSTs (right) over 1981-2005 (after Rodwell and Folland, 2002). The pair explains 23% of the covariance.





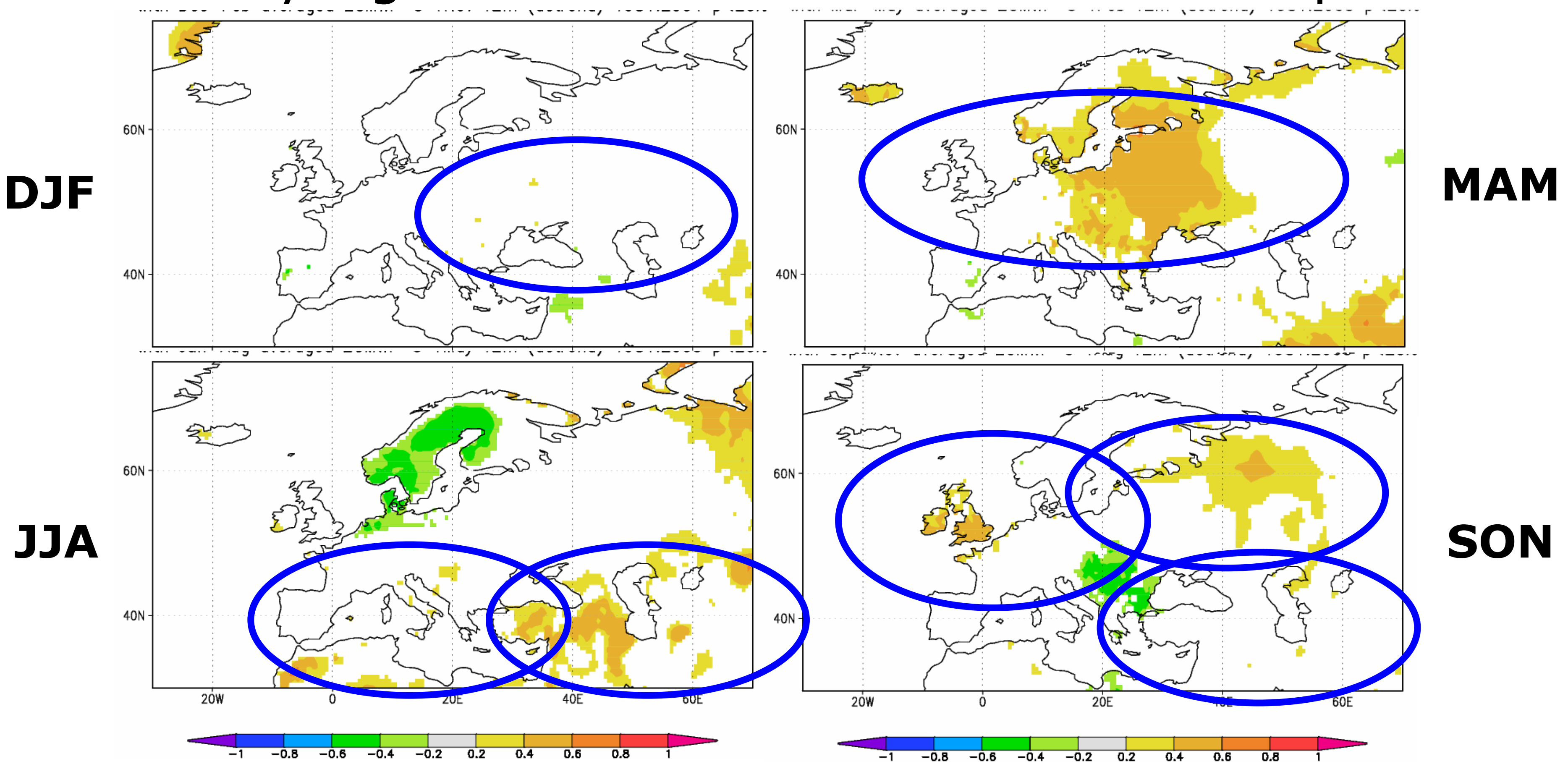
Extratropical SSTs: the North Atlantic

Leading pairs of the MCA between System 3 one-month lead DJF MSLP (left) and the leading May North Atlantic HadISST1 SSTs (right) over 1981-2005. The pairs explain 14% and 12% of the covariance, respectively.



Impact of the trend: temperature

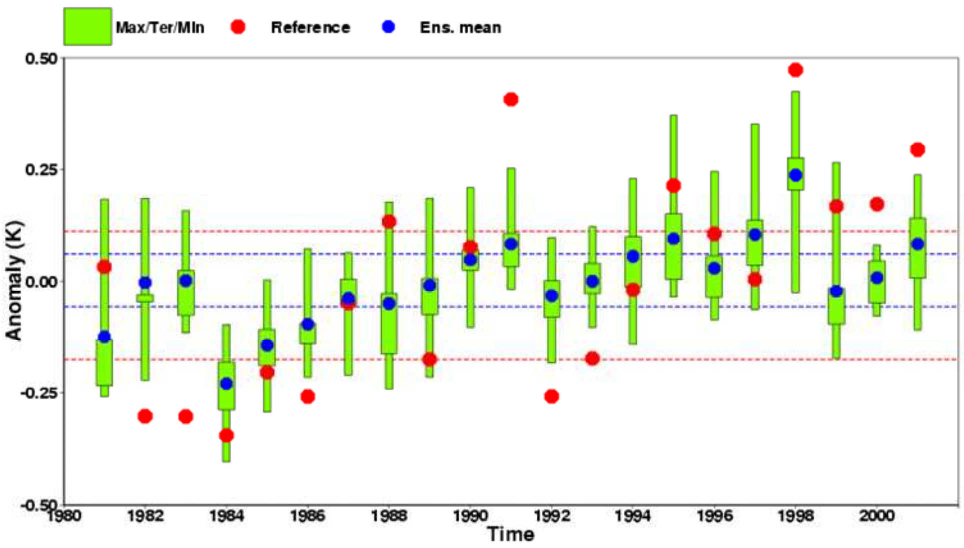
Correlation of System 3 seasonal forecasts of detrended temperature wrt GHCN over 1981-2005. Only values statistically significant with 80% confidence are plotted.



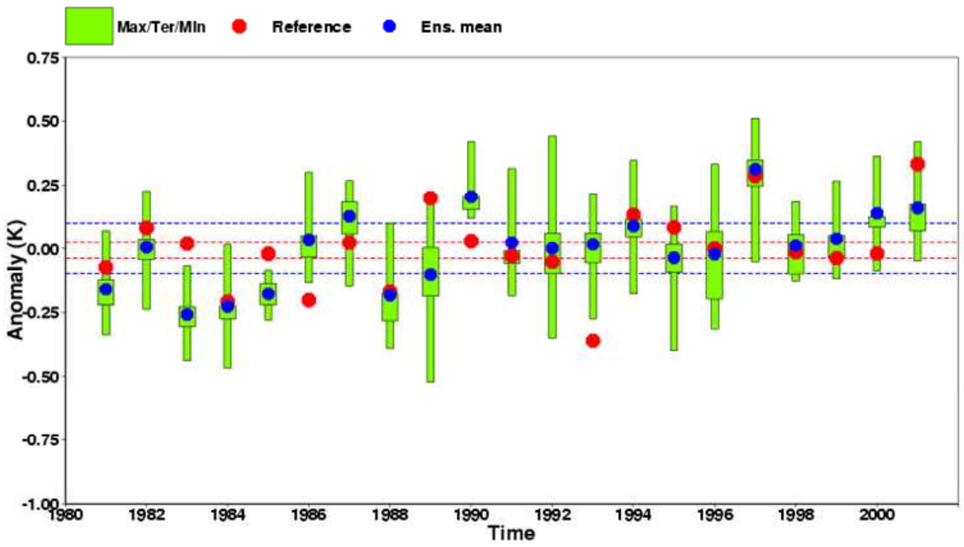
Temperature: global trend

Global-mean near-surface air temperature for System 3. The green box-and-whisker plots show the ensemble range, the blue dot the ensemble mean and the red dot the ERA40/ERAInt value.

JJA
Ratio sd: 0.59
Corr: 0.69



DJF
Ratio sd: 1.26
Corr: 0.44



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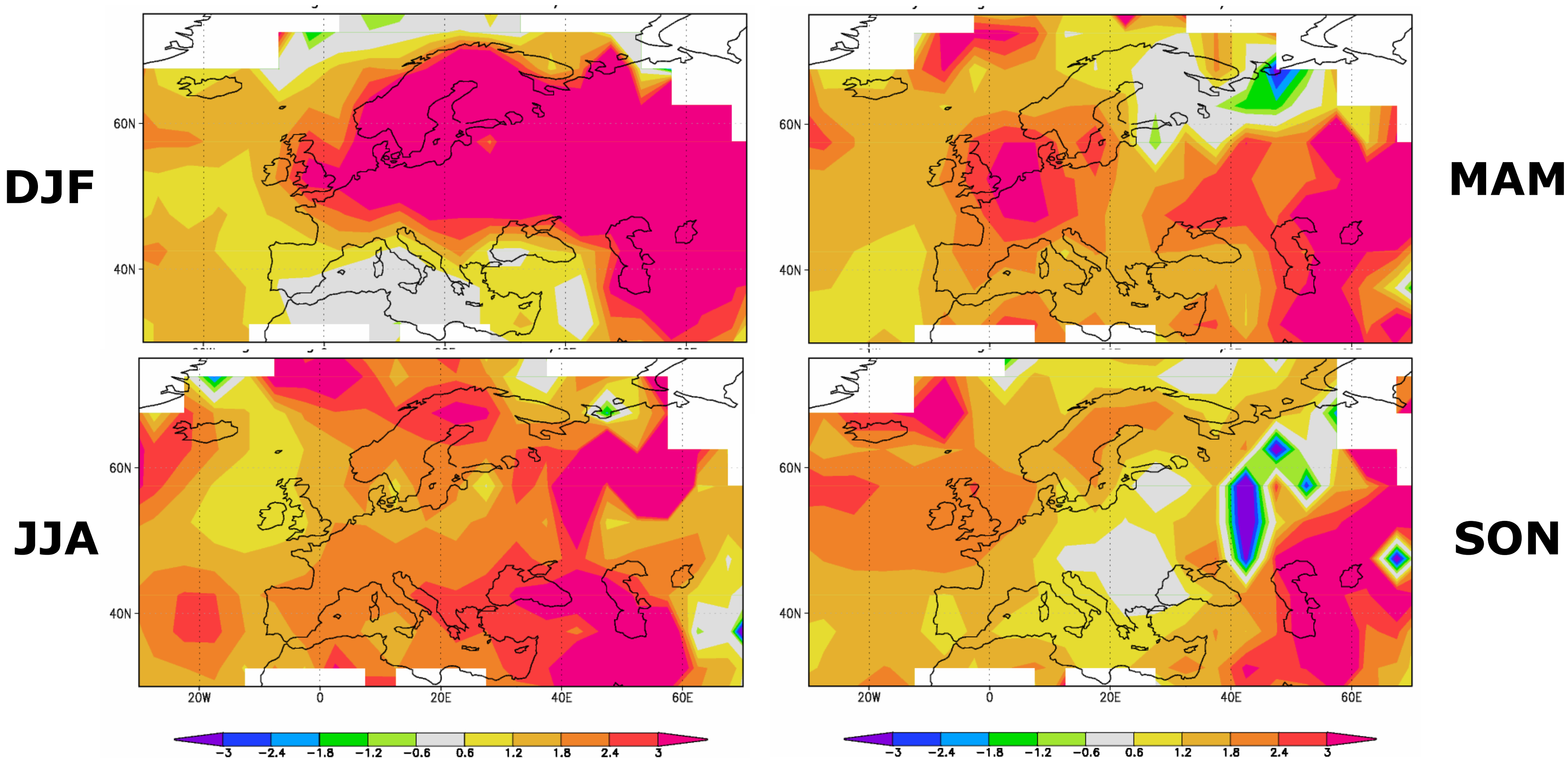
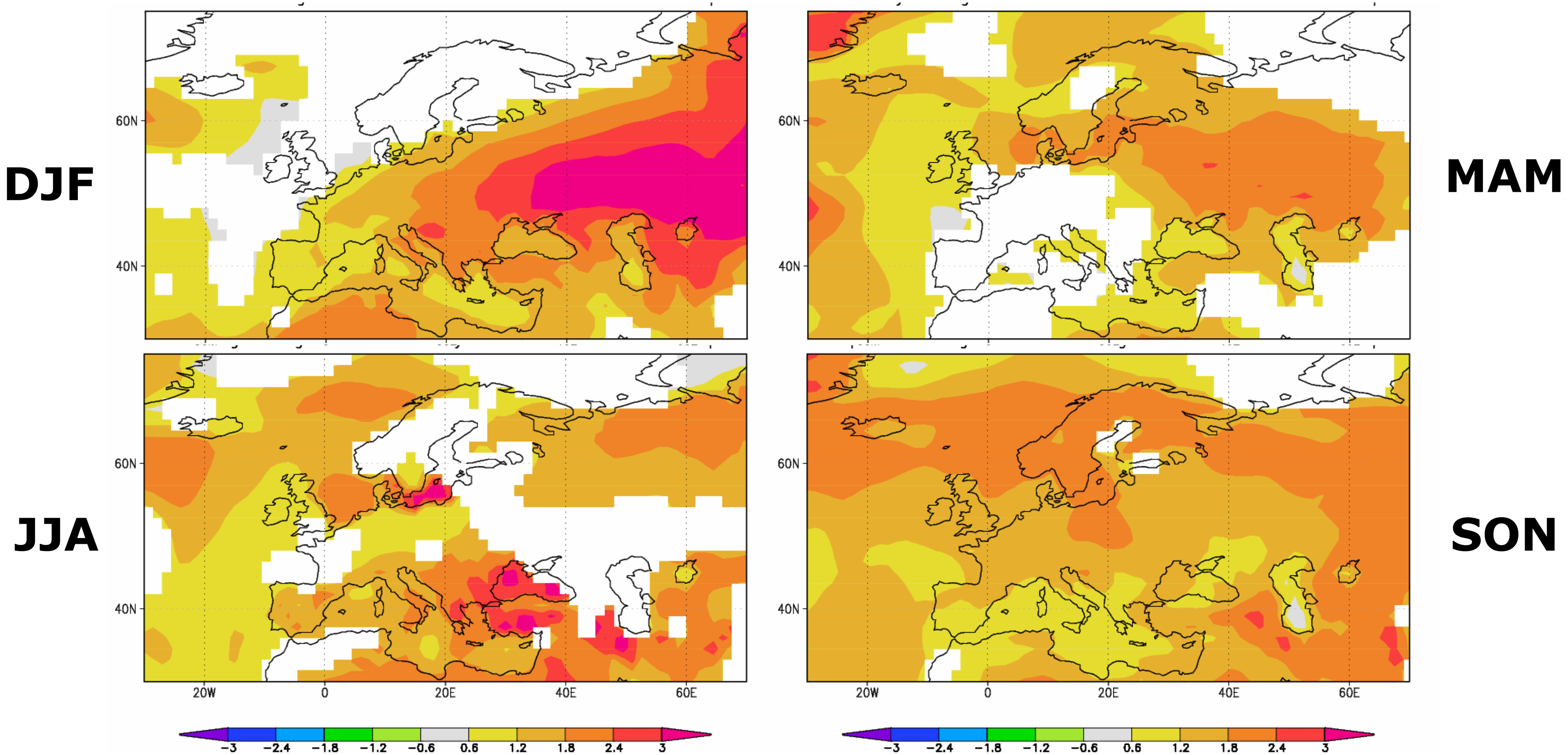
Temperature: impact of the trend

Regression of CRUTEM3/HadSST2 temperature with the HadCRUT3 global-mean temperature over 1981-2005.



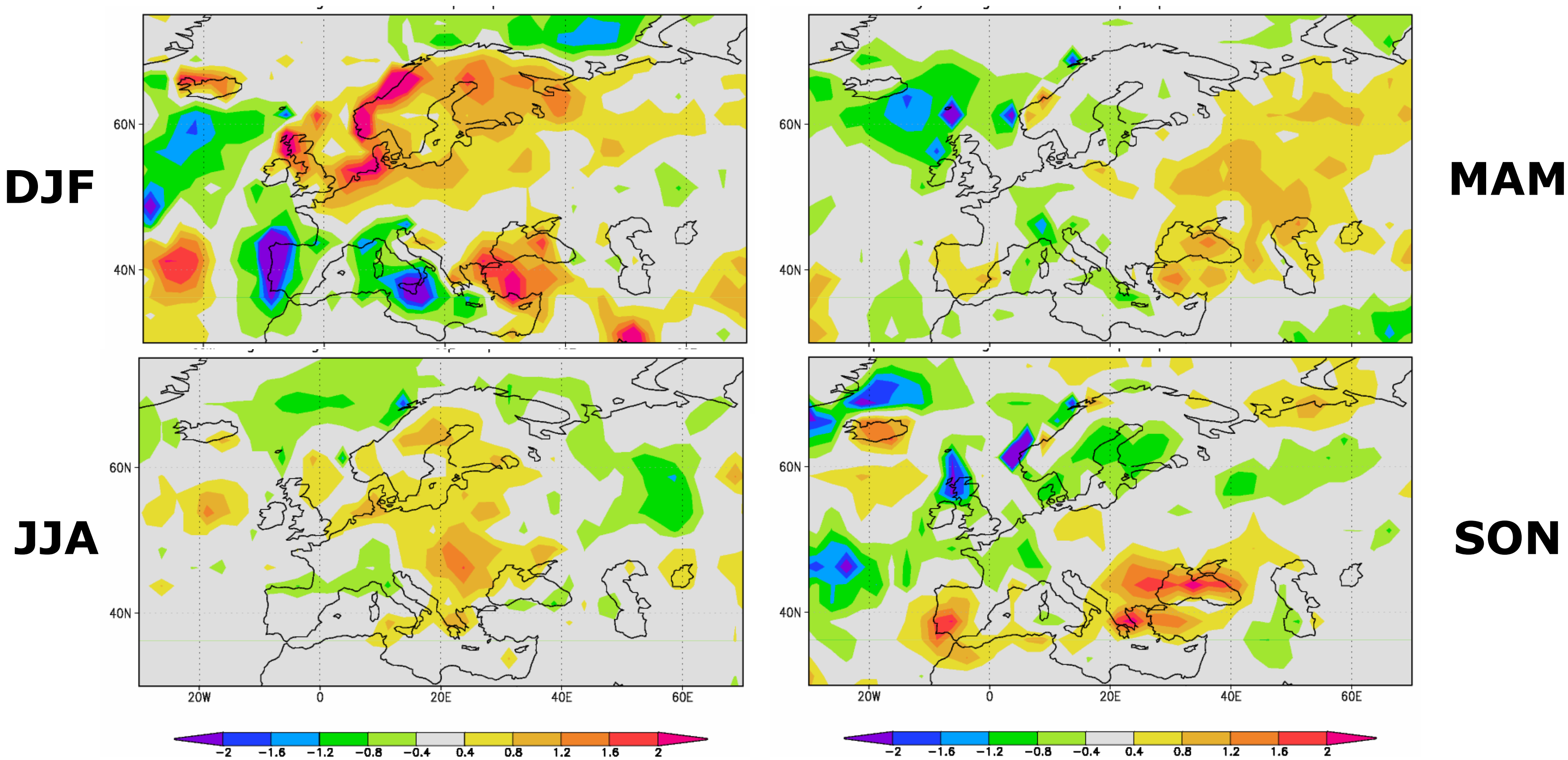
Temperature: impact of the trend

Regression of System 3 temperature seasonal forecasts on the global-mean temperature over 1981-2005. Only values statistically significant with 80% confidence are plotted.



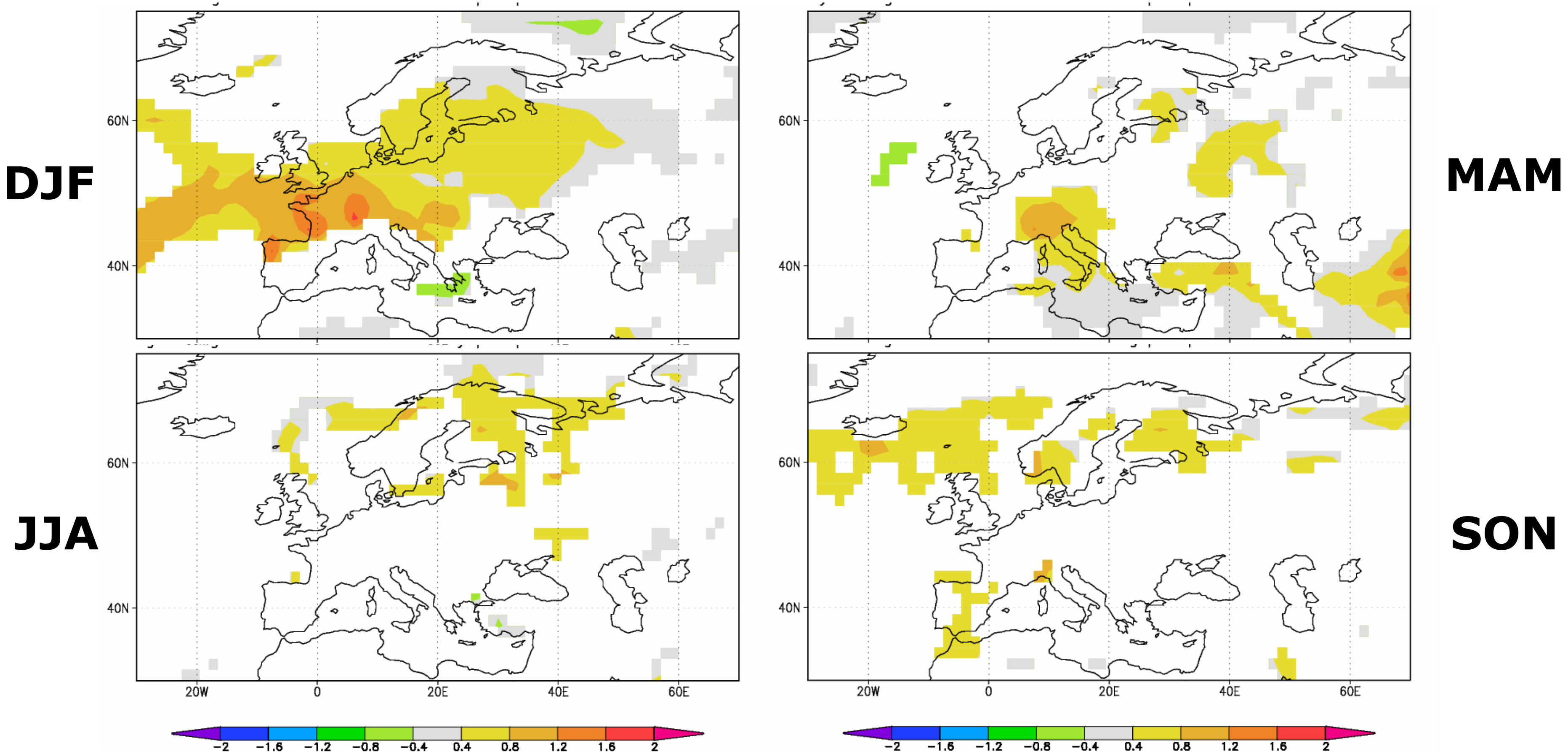
Precipitation: impact of the trend

Regression of GPCP precipitation with the HadCRUT3 global-mean temperature over 1981-2005.



Precipitation: impact of the trend

Regression of System 3 seasonal forecasts precipitation on the global-mean temperature over 1981-2005. Only values statistically significant with 80% confidence are plotted.



Model inadequacy: ENSEMBLES

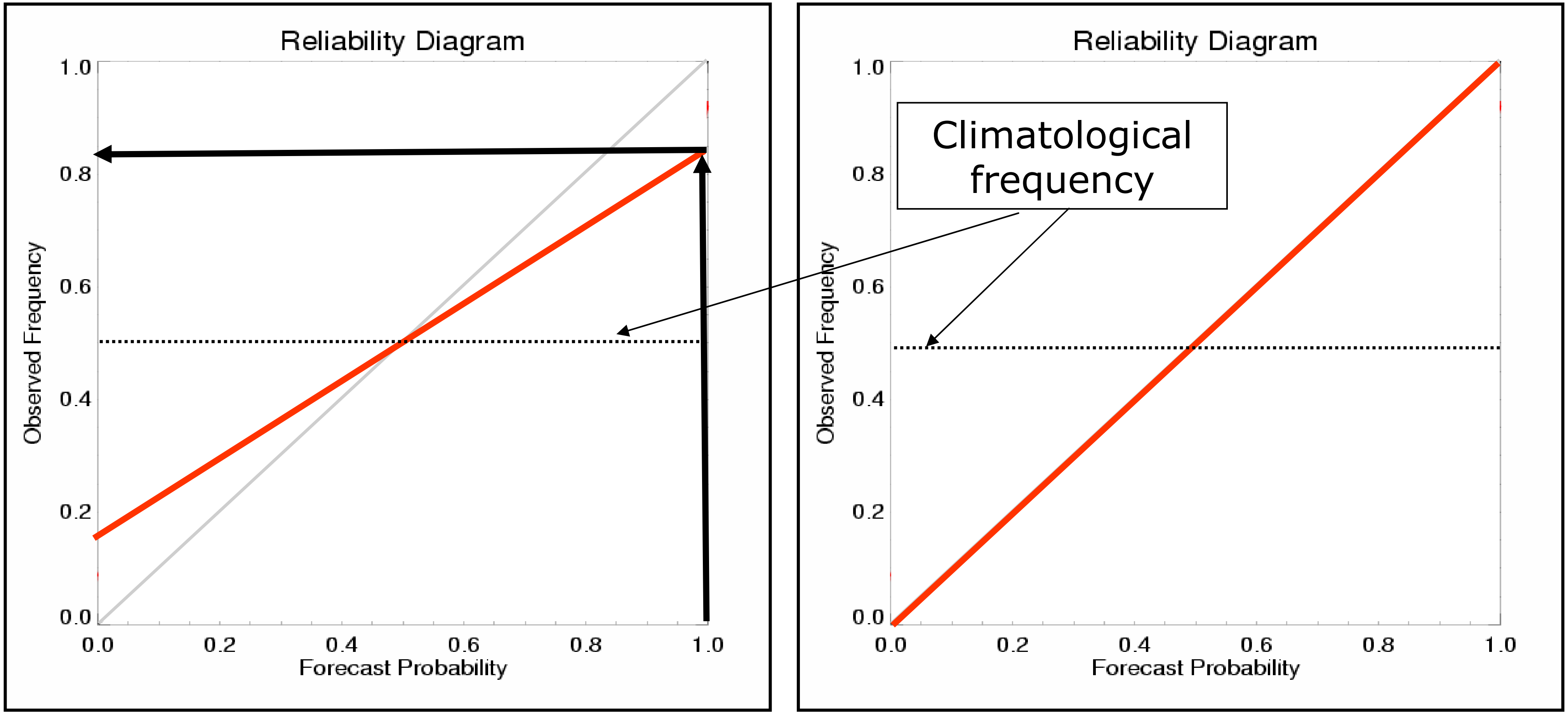
- Common experimental set-up with realistic initialization using multi-model, perturbed parameters and stochastic physics
  - Seasonal and annual (14 months) hindcasts
  - Two streams
    - Stream 1: 1991-2001, May and Nov start dates, nine members
    - Stream 2: 1960-2005, 4 start dates per year for seasonal/annual (9 members)

ENSEMBLES contributors

partner	Atmospheric model; resolution	Ocean model; resolution	initialization		external forcing	Additional components, comments	references
			atmosphere and land	ocean			
ECMWF	IFS CY31R1; T159/L62	HOPE; 0.3º-1.4º/L29	ERA-40/oper. analysis, atmospheric singular vectors	wind stress perturbations to generate ensemble of ocean reanalyses; SST perturbations at initial time	observed global well-mixed GHGs and sulphate aerosol and A1B from 2000, observed solar activity, no volcanic aerosol nor ozone	Operational Seasonal Forecasting system S3	*Stockdale et al.* (2010)*; Balmaseda et al.* (2008)
	IFS CY33R1; T159/L62	HOPE; 0.3º-1.4º/L29	ERA-40/oper. analysis, atmospheric singular vectors	wind stress perturbations to generate ensemble of ocean reanalyses; SST perturbations at initial time	"	used for the decadal hindcasts only	*Bechtold et al. (2008)*
	IFS CY35R2; T159/L62	HOPE; 0.3º-1.4º/L29	ERA-40/oper. analysis, atmospheric singular vectors	wind stress perturbations to generate ensemble of ocean reanalyses; SST perturbations at initial time	"	used with the stochastic physics approach	*Palmer et al. (2009)*
UKMO	HadGEM2-A; N96/L38	HadGEM2-O; 0.33º-1º/L20	ERA-40/oper. analysis, anomaly assimilation for soil moisture	wind stress perturbations to generate ensemble of ocean reanalyses; SST perturbations at initial time	observed global well-mixed GHGs, ozone and sulphate aerosol emissions and A1B from 2000, persisted solar activity and volcanic aerosol	fully interactive sea ice module	*Collins et al.* (2008)
	HadAM3; 3.75x2.5°	HadOM	anomaly assimilation of ERA-40/oper. analysis	anomaly assimilation of an ocean reanalysis	"	perturbed-parameter ensemble	*Smith et al.* (2007)
MF	ARPEGE4.6; T63	OPA8.2; 2˚/L31	ERA-40/oper. analysis	wind stress, SST and water flux perturbations to generate ensemble of ocean reanalyses	observed global well-mixed GHGs and sulphate aerosol and A1B from 2000, no solar activity nor volcanic aerosol, dynamical ozone	GELATO sea ice model	*Daget et al.* (2009)*; Salas y Melia* (2002)
IFM-GEOMAR	ECHAM5; T63/L31	MPI-OM1; 1.5º/L40	initial condition permutations of three coupled climate simulations from 1950 to 2005 with SSTs restored to observations		observed global well-mixed GHGs, ozone and sulphate aerosol emissions and A1B from 2000, persisted solar activity and volcanic aerosol	-	*Keenlyside et al.* (2005)*; Jungclaus et al.* (2006)
CMCC-INGV	ECHAM5; T63/L19	OPA8.2; 2˚/L31	AMIP-type simulations with forced SSTs	wind stress perturbations to generate ensemble of ocean reanalyses, SST perturbations at initial time	observed global well-mixed GHGs and sulphate aerosol and A1B from 2000, no volcanic aerosol nor ozone	dynamical snow-sea ice model and land-surface model	*Weisheimer et al.* (2009); *Alessandri et al.* (2010)

Reliability diagram

Forecast reliability measures conditional biases of forecast probabilities; example for event "values above the median"



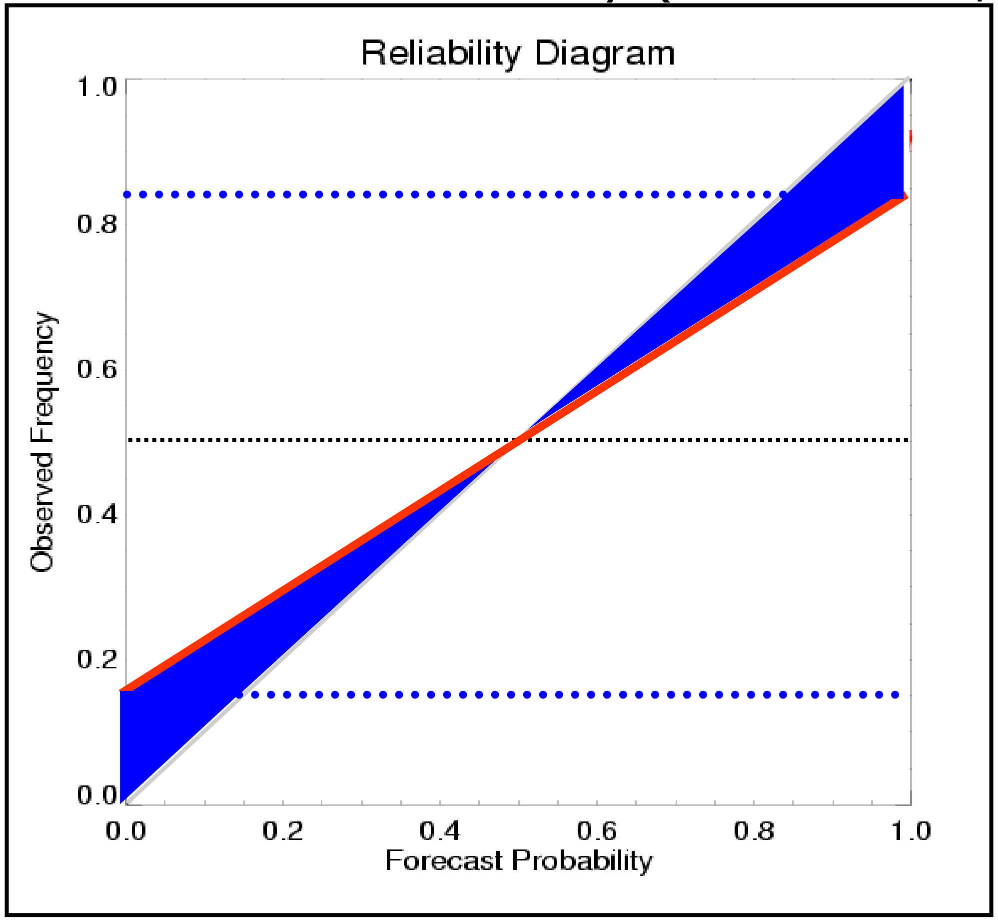
Overconfident

Perfect reliability

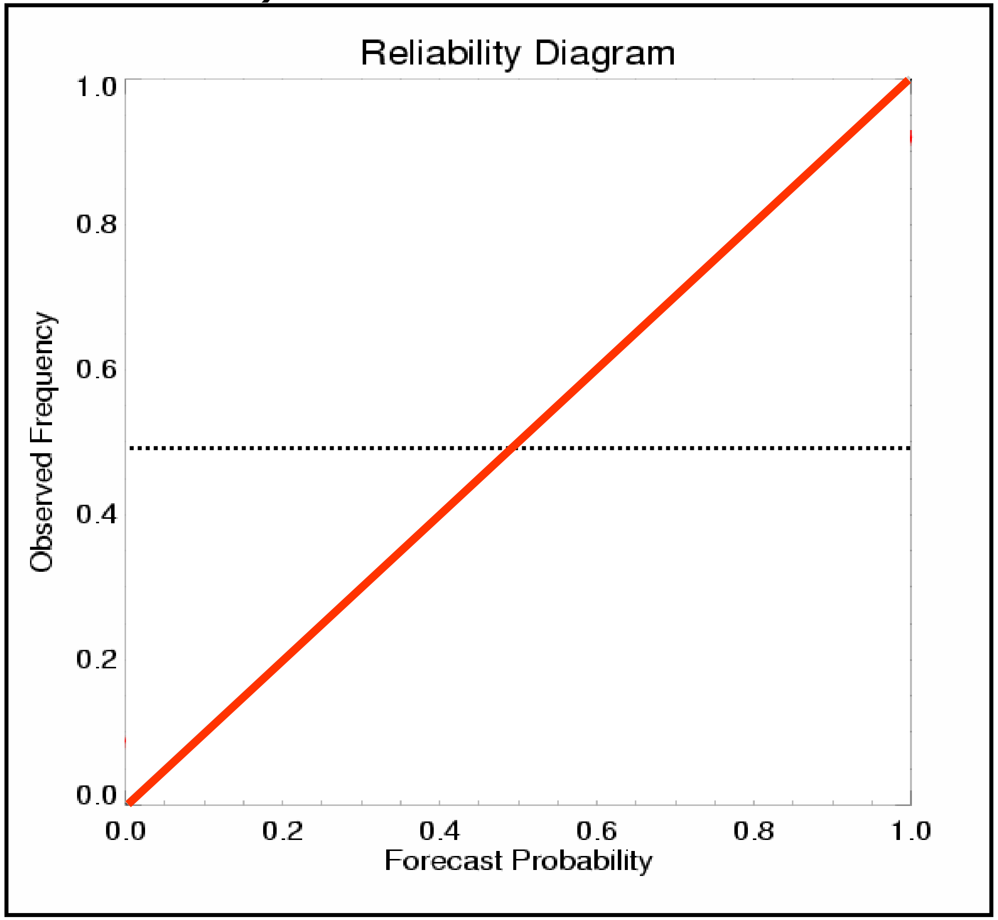
Reliability diagram

Forecast reliability measures conditional biases of forecast probabilities

Reliability (the smaller, the better)



Overconfident

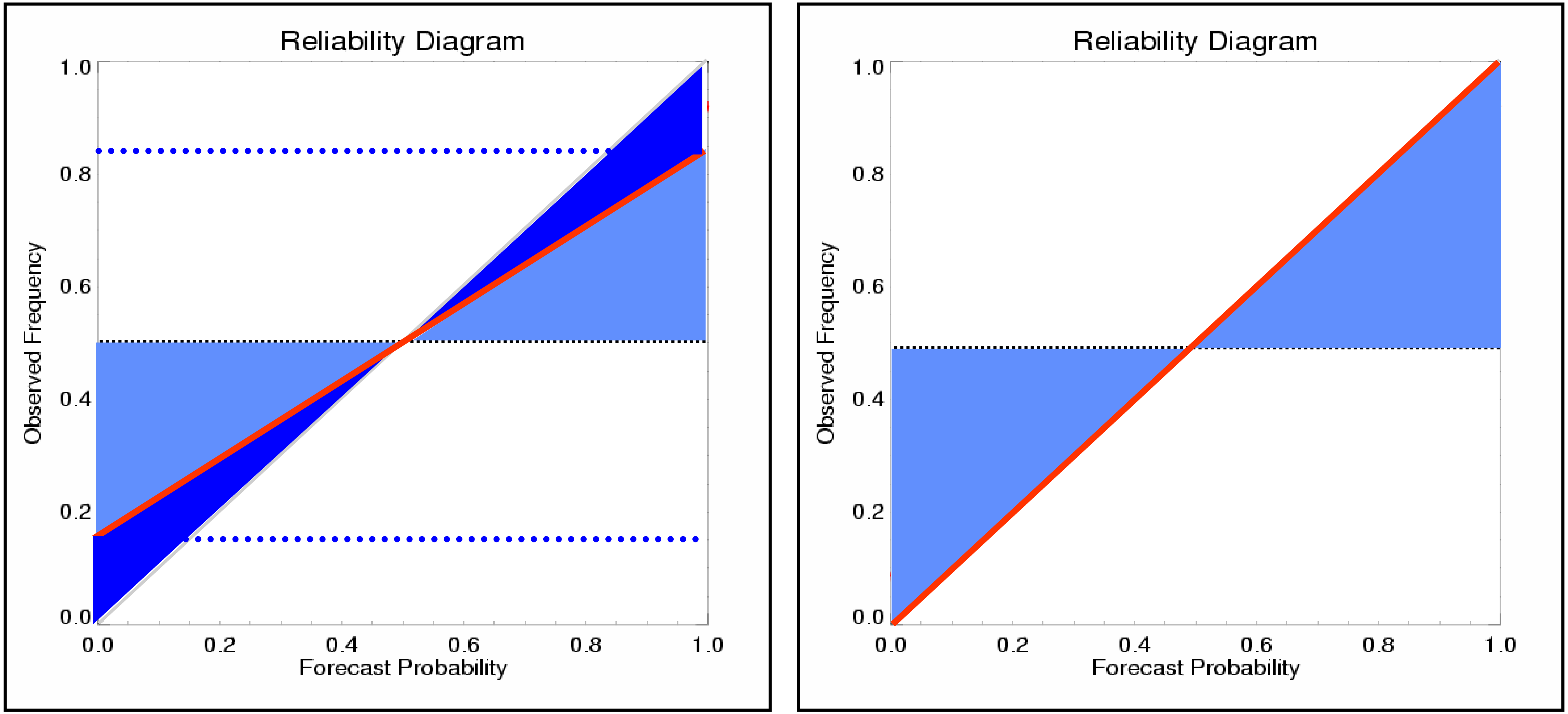


Perfect reliability

Reliability diagram

Reliability score (the smaller, the better)

Resolution score (the bigger, the better)

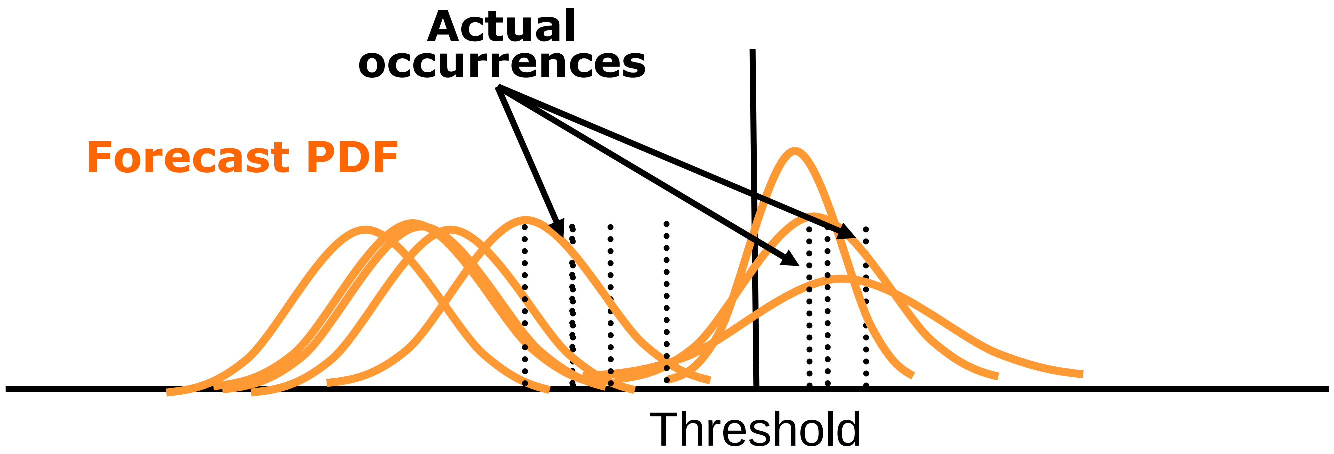


Overconfident

Perfect reliability

Reliability in probability forecasts

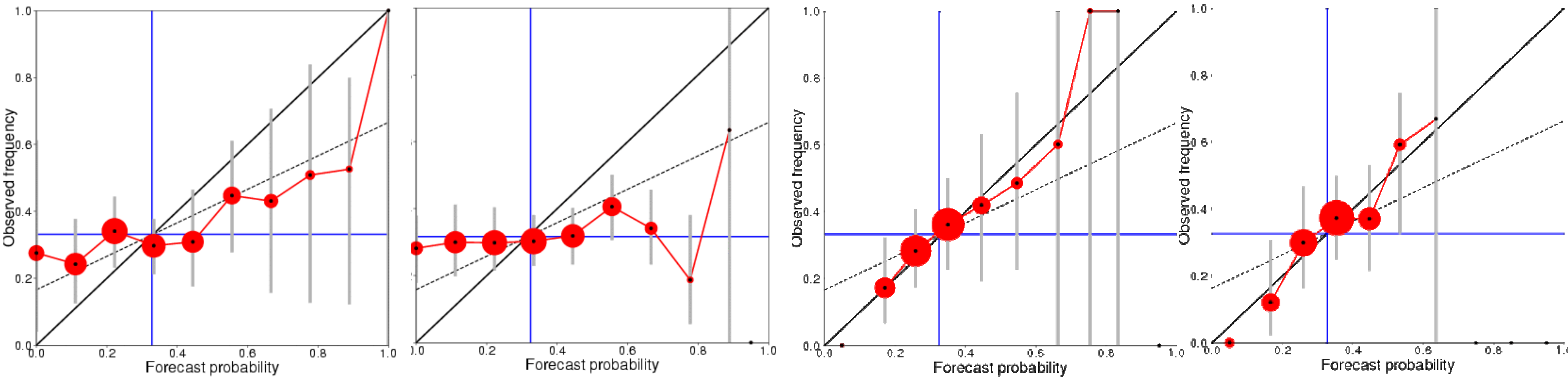
- Reliability is a property of a forecast system that measures the ability to issue trustworthy probabilities
  - A probabilistic model is required to go from the ensemble members to probability forecasts (using e.g., probabilities as the proportion of ensemble members beyond a threshold, dressing).
  - Forecast reliability measures the conditional biases of the forecast probabilities and is part of the systematic error of the forecast system.
  - Reliability for dichotomous events is best illustrated in an attributes diagram (made of a reliability diagram and a probability histogram).



Multi-model improvement

Attribute diagrams for one-month lead seasonal (DJF) temperature over Southern Europe for System 3 (left, 9 members) and the ENSEMBLES Stream 2 multi-model (right, 45 members) over the period 1981-2005 verified against ERA40. Brier and ROC skill scores and 95% confidence intervals (in brackets) computed using a bootstrap method, are shown on top of each panel.

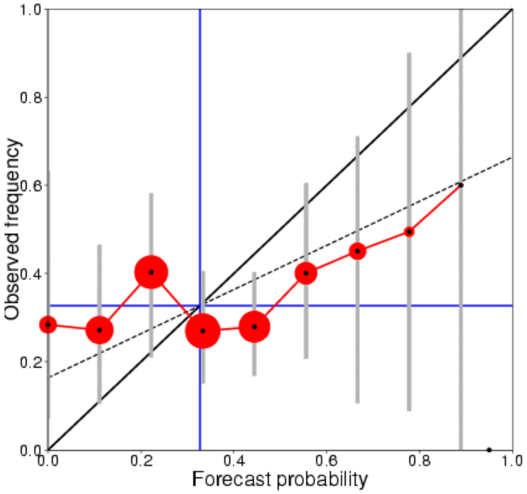
System 3		Multi-model	
Above upper tercile	Below lower tercile	Above upper tercile	Below lower tercile
-.078 (-.287,.093)	-.140 (-.348,.022)	.054 (-.063,.140)	.047 (-.050,.106)
.148 (-.073,.379)	.109 (-.095,.325)	.256 (-.004,.464)	.253 (.027,.460)

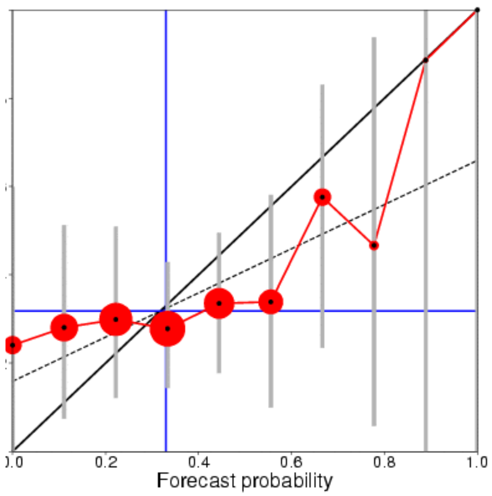


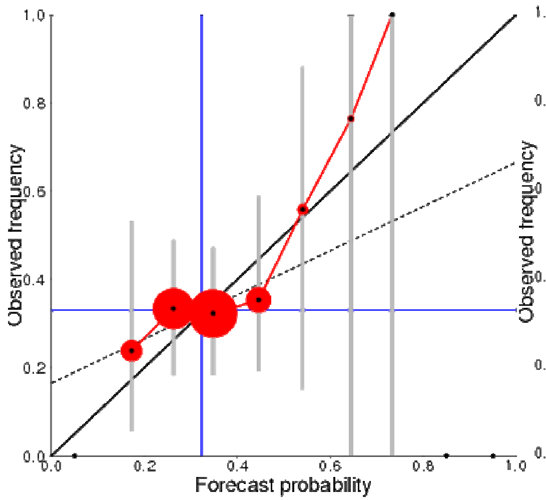
Multi-model improvement

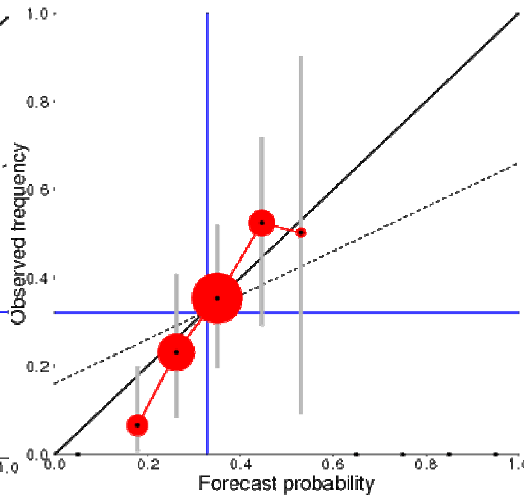
Attribute diagrams for one-month lead seasonal (DJF) temperature over Northern Europe for System 3 (left, 9 members) and the ENSEMBLES Stream 2 multi-model (right, 45 members) over the period 1981-2005 verified against ERA40. Brier and ROC skill scores and 95% confidence intervals (in brackets) computed using a bootstrap method, are shown on top of each panel.

System 3		Multi-model	
Above upper tercile	Below lower tercile	Above upper tercile	Below lower tercile
-.102 (-.289,.017)	-.057 (-.322,.098)	-001 (-.133,.047)	.056 (-.101,.093)
.052 (-.179,.274)	.134 (-.182,.434)	.087 (-.101,.265)	.326 (-.119,.516)





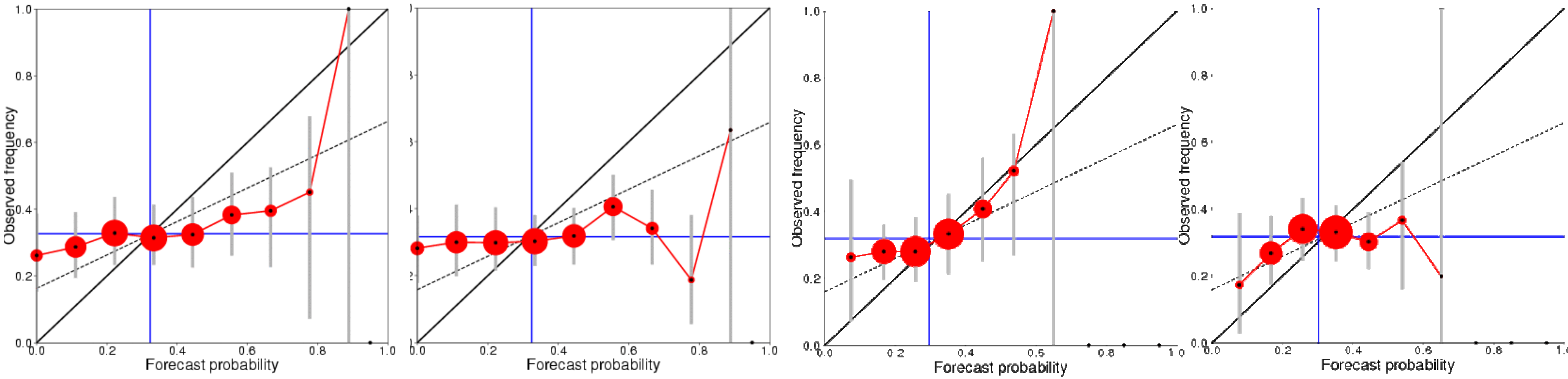




Multi-model improvement

Attribute diagrams for one-month lead seasonal (JJA) precipitation over Southern Europe for System 3 (left, 9 members) and the ENSEMBLES Stream 2 multi-model (right, 45 members) over the period 1981-2005 verified against GPCP. Brier and ROC skill scores and 95% confidence intervals (in brackets) computed using a bootstrap method, are shown on top of each panel.

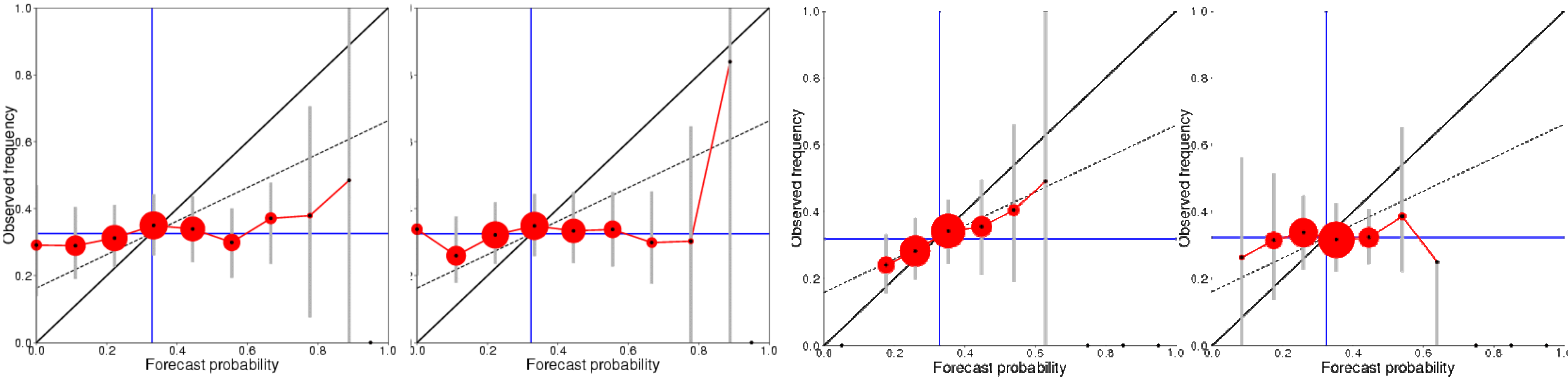
System 3		Multi-model	
Above upper tercile	Below lower tercile	Above upper tercile	Below lower tercile
-.088 (-.167,-.038)	-.118 (-.178,-.071)	.001 (-.069,.046)	-.031 (-.082,.002)
.075 (-.027,.175)	.081 (-.018,.140)	.133 (-.022,.274)	.051 (-.070,.174)



Multi-model improvement

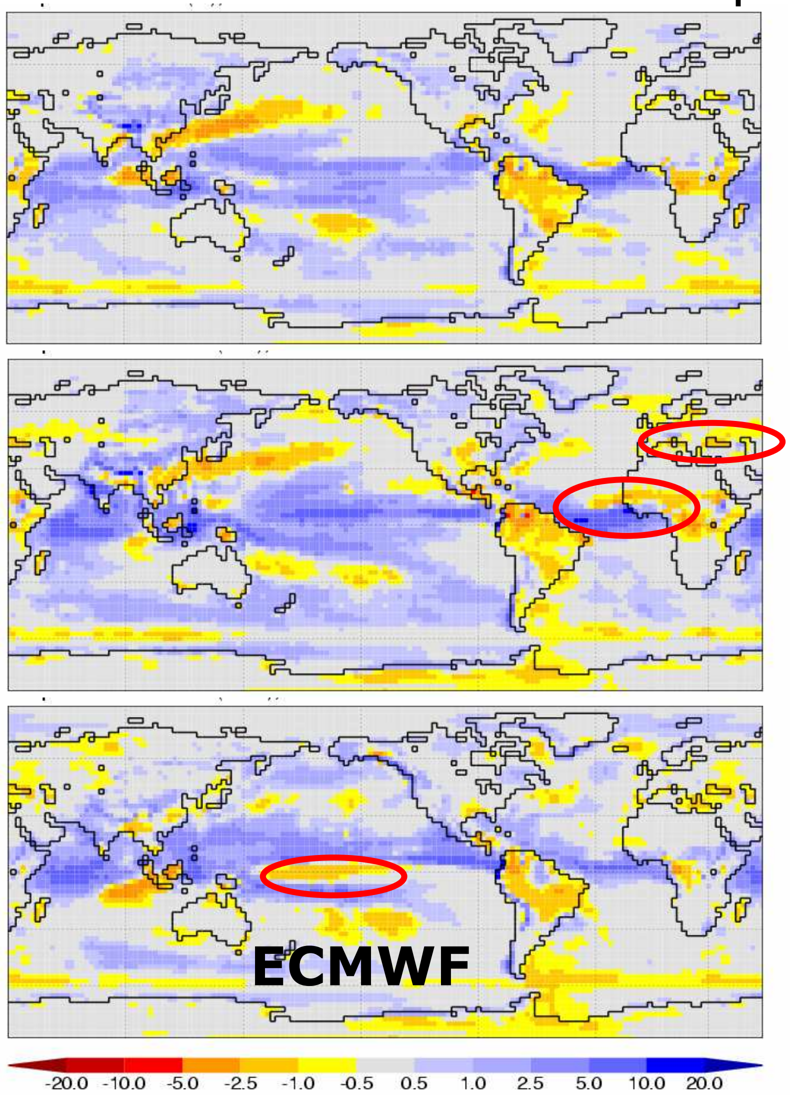
Attribute diagrams for one-month lead seasonal (JJA) precipitation over Northern Europe for System 3 (left, 9 members) and the ENSEMBLES Stream 2 multi-model (right, 45 members) over the period 1981-2005 verified against GPCP. Brier and ROC skill scores and 95% confidence intervals (in brackets) computed using a bootstrap method, are shown on top of each panel.

System 3		Multi-model	
Above upper tercile	Below lower tercile	Above upper tercile	Below lower tercile
-.101 (-.181,-.059)	-.101 (-.180,-.055)	-.004 (-.081,.030)	-.034 (-.102,-.001)
.039 (-.052,.113)	.039 (-.055,.123)	.127 (-.001,.247)	-.005 (-.138,.143)



Commonality of systematic errors

ENSEMBLES Stream 2 precip. mean bias wrt GPCP, 1979-2005



First month

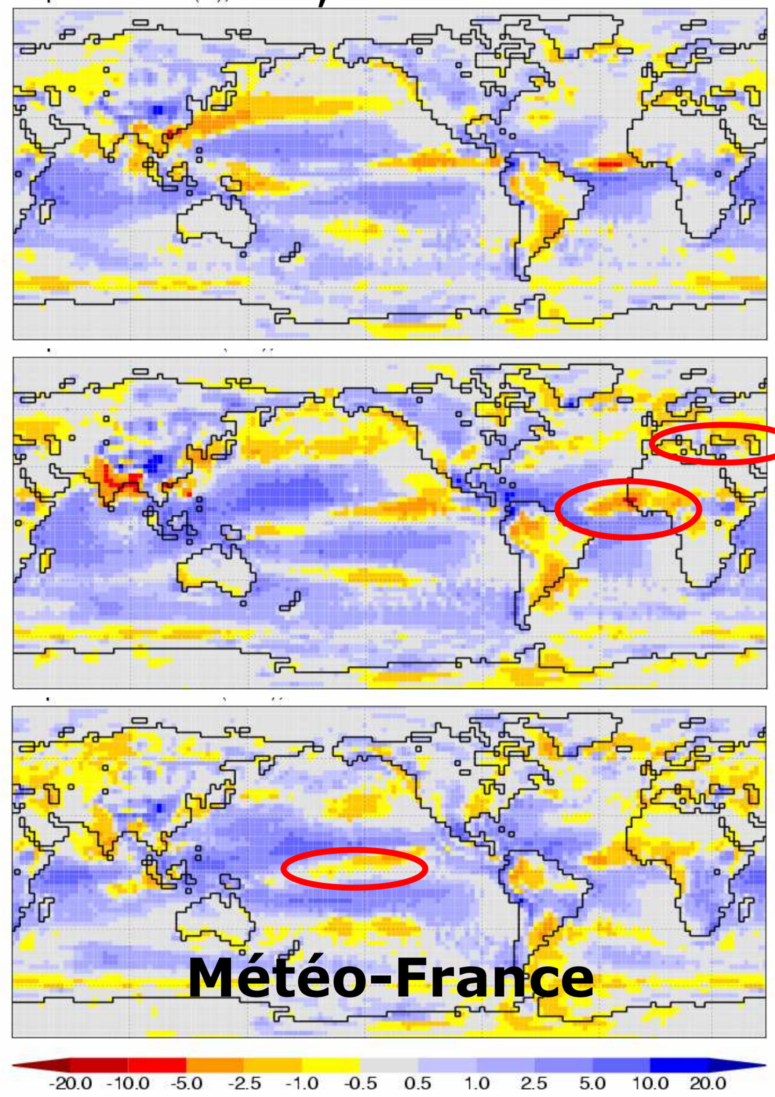
May

Months 2-4

JJA

Months 5-7

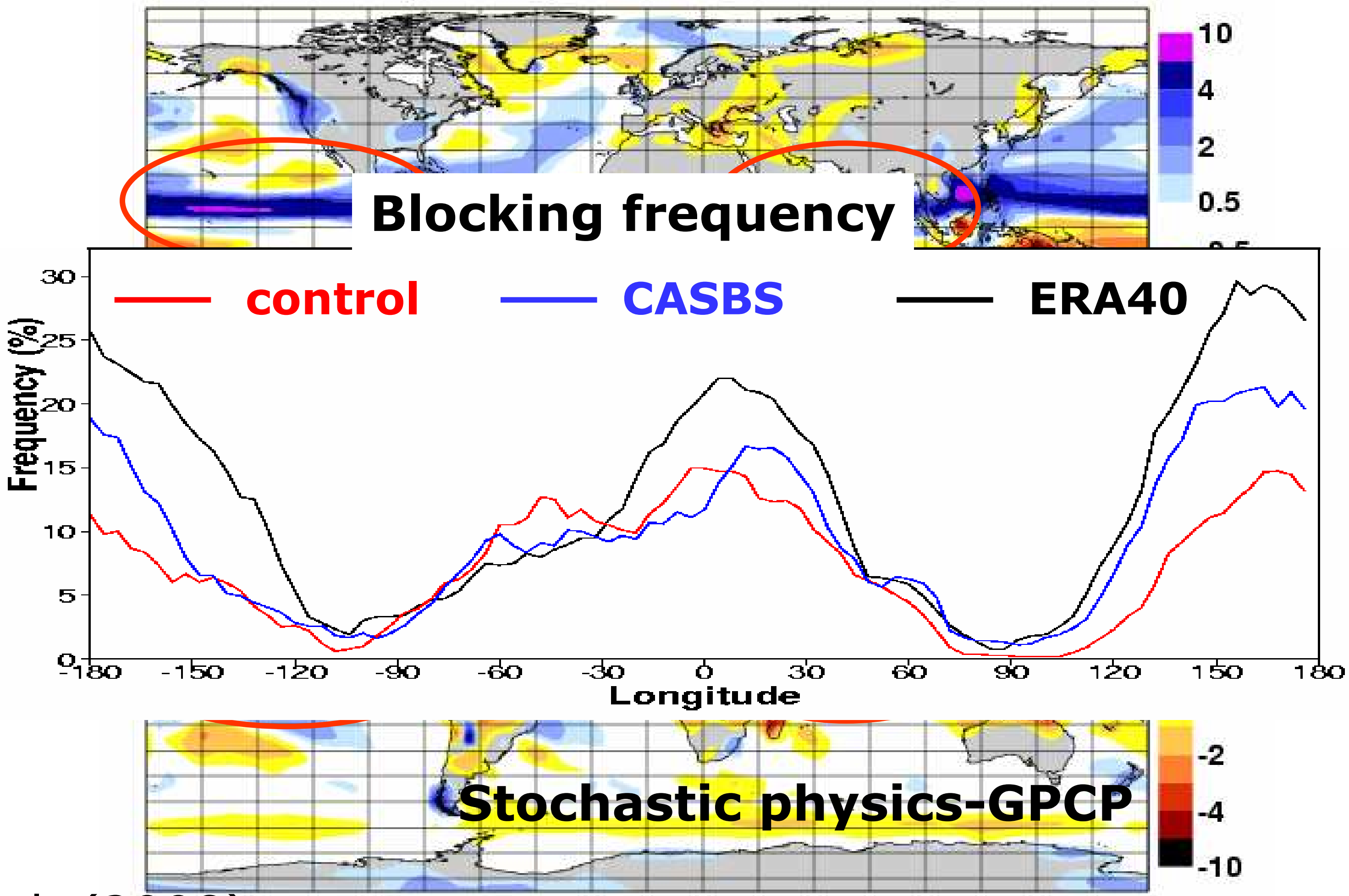
SON



Error reduction: stochastic physics

Precipitation bias (DJF, 1-month lead, 1991-2001, CY29R2)

CASBS reduces the tropical and blocking frequency biases



Berner et al. (2008)

Dealing with model inadequacy

Debiased Brier skill score of one-month lead predictions of land temperature over the Giorgi regions for Multi-model (45 members, left columns), Perturbed parameters (9 members, central columns) and Stochastic physics (9 members, right columns) over 1991-2005. Significantly positive or negative scores are in bold.

	NEAR-SURFACE TEMPERATURE											
	multi-model				perturbed parameters				stochastic physics			
	JJA		DJF		JJA		DJF		JJA		DJF	
	cold	warm	cold	warm	cold	warm	cold	warm	cold	warm	cold	warm
Australia	**11.5**	**13.9**	3.2	6.7	-0.3	**11.0**	0.5	5.2	7.0	**17.3**	**11.8**	8.0
Amazon Basin	0.2	17.1	4.5	**23.4**	-13.7	2.8	-6.3	11.2	3.9	14.7	2.6	16.9
Southern South America	**9.2**	**9.0**	1.8	**9.9**	-2.8	7.2	2.9	**14.7**	**16.9**	8.8	4.5	**9.3**
Central America	5.9	**11.6**	-2.6	4.5	2.4	5.5	-3.9	3.3	1.2	-0.3	0.2	-3.7
Western North America	10.2	**12.2**	6.3	**12.5**	6.7	-1.2	3.3	8.9	2.8	8.0	6.4	4.7
Central North America	-0.2	**-7.3**	-3.3	10.4	-8.5	**-12.7**	7.2	13.8	**-21.4**	**-20.3**	-2.6	8.8
Eastern North America	4.1	-7.0	-4.5	10.1	-9.9	-14.7	**32.2**	8.2	-13.4	**-10.9**	-11.3	4.0
Alaska	-0.8	-0.9	-0.6	0.6	-0.4	-2.9	6.5	4.8	0.5	**12.2**	**-20.3**	-1.0
Greenland	**15.1**	**8.7**	**13.2**	**12.3**	12.7	1.5	**17.3**	**15.1**	3.2	3.1	**12.3**	**16.3**
Mediterranean	**18.0**	**12.8**	5.8	4.3	**18.3**	**15.5**	**-17.5**	**-14.5**	**22.7**	**12.2**	6.2	2.6
Northern Europe	-3.3	0.2	4.9	0.5	1.1	4.6	-0.6	-4.0	4.6	6.3	1.5	5.2
Western Africa	7.9	7.0	7.3	**20.5**	14.8	3.0	3.6	10.0	7.8	2.0	10.9	**15.8**
Eastern Africa	**9.4**	**7.3**	-7.7	0.9	**-19.5**	-7.1	-3.9	-5.4	**-9.7**	-3.1	-3.7	8.2
Southern Africa	**14.0**	4.7	1.7	**10.6**	-3.2	10.2	-1.7	2.7	0.0	7.7	6.0	**13.6**
Sahel	**12.9**	7.2	**11.5**	**15.4**	**9.9**	**13.1**	6.6	**15.7**	**16.3**	**10.1**	**13.9**	**14.7**
South East Asia	**8.6**	**12.4**	**11.6**	13.4	-9.3	4.2	13.9	6.1	-0.6	9.6	3.8	1.6
East Asia	10.6	**10.2**	0.3	5.8	8.3	**10.5**	-4.2	10.1	6.4	**14.1**	3.1	-0.4
South Asia	**8.7**	**13.3**	**14.4**	**10.6**	4.3	9.2	0.1	9.3	12.9	**15.7**	**13.8**	**18.1**
Central Asia	**14.3**	**8.2**	-2.4	7.1	**14.1**	**11.8**	-2.0	**19.1**	**21.1**	**10.1**	-8.5	6.5
Tibet	**16.9**	**16.1**	-0.1	4.1	7.8	7.2	**-10.4**	3.8	8.3	**15.7**	5.6	7.6
North Asia	**7.3**	3.9	4.2	**8.5**	6.2	**8.4**	-1.5	**12.6**	4.2	1.6	-1.9	1.2

Dealing with model inadequacy

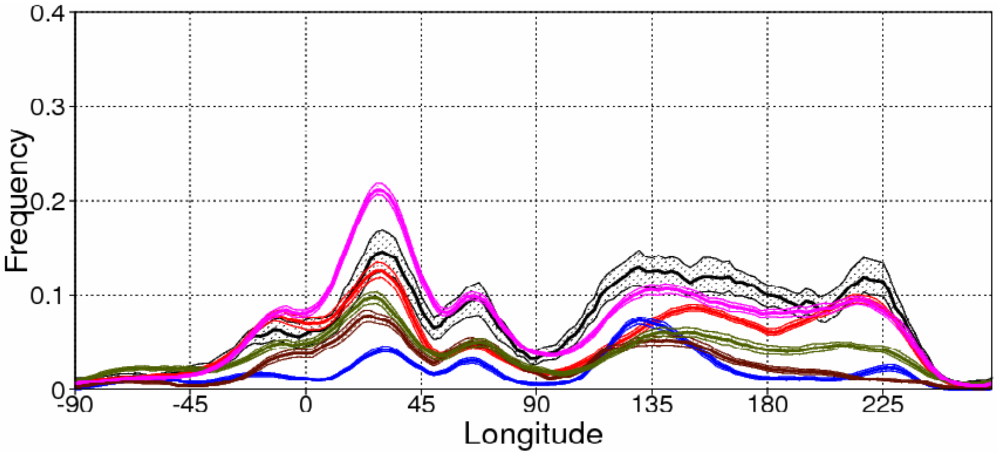
Debiased Brier skill score of one-month lead predictions of land temperature over the Giorgi regions for Multi-model (45 members, left columns), Perturbed parameters (9 members, central columns) and Stochastic physics (9 members, right columns) over 1991-2005. Significantly positive or negative scores are in bold.

	PRECIPITATION											
	JJA		DJF		JJA		DJF		JJA		DJF	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
Australia	7.6	7.0	0.9	3.0	5.1	8.0	**12.4**	5.2	2.5	5.0	**10.5**	6.6
Amazon Basin	**10.3**	**10.3**	**16.0**	14.3	**8.8**	5.4	3.4	0.5	**12.2**	**11.4**	**16.1**	16.8
Southern South America	6.2	7.1	4.6	6.0	1.3	1.6	-4.5	-1.7	3.3	**9.0**	-4.7	0.2
Central America	**9.2**	**7.8**	**23.4**	**18.9**	**12.9**	5.2	**23.3**	**25.9**	**10.6**	7.7	**24.9**	**23.7**
Western North America	2.4	**8.1**	**7.2**	**7.8**	4.5	**7.5**	4.5	4.9	**9.1**	**8.4**	5.7	5.3
Central North America	0.6	2.2	7.7	**10.4**	-3.5	-5.7	**10.0**	**10.4**	1.7	3.0	2.1	5.5
Eastern North America	-1.9	-1.1	**8.3**	**10.6**	**-9.6**	**-11.1**	9.7	**13.2**	**-15.0**	-6.8	7.5	2.1
Alaska	-1.3	0.0	4.0	-2.2	-2.3	-1.0	**11.3**	3.7	-4.3	-0.7	0.2	-2.5
Greenland	2.6	**2.8**	**-3.7**	**-3.0**	1.4	0.2	**7.5**	-1.7	**-6.8**	-2.6	-2.2	-2.1
Mediterranean	-1.2	1.2	-1.0	-1.3	-6.1	-4.4	-3.0	0.1	-0.9	0.1	**11.5**	10.7
Northern Europe	2.3	2.1	-3.1	**-4.7**	**7.7**	**11.5**	-1.8	-1.6	**8.2**	6.0	6.6	1.6
Western Africa	-1.5	-0.1	-0.5	1.3	**-10.9**	-3.8	4.8	-1.0	-4.8	2.4	**-13.7**	-0.1
Eastern Africa	-2.8	1.8	3.9	2.5	-7.0	**-7.6**	**14.4**	**13.2**	-1.5	3.4	0.9	5.7
Southern Africa	3.5	1.0	5.7	**9.5**	**7.2**	4.7	**6.0**	**11.3**	7.8	9.2	7.7	8.9
Sahel	**-4.6**	**-3.6**	**-3.2**	-1.5	**-9.2**	**-6.7**	-2.7	-2.4	**-10.0**	-1.0	**-8.2**	-3.6
South East Asia	**14.3**	9.7	**8.8**	**8.3**	5.5	4.8	5.6	8.3	10.3	1.1	9.6	**12.5**
East Asia	0.5	-0.5	4.7	**4.6**	**5.6**	1.4	8.9	3.6	2.8	0.6	8.9	**15.7**
South Asia	0.2	0.9	**6.5**	**7.4**	0.6	-2.7	7.0	9.4	2.7	1.9	5.5	**10.2**
Central Asia	-0.8	0.2	7.4	5.7	0.8	-3.1	**10.3**	**8.4**	-1.5	0.2	2.9	1.6
Tibet	5.5	3.5	**6.5**	5.4	-1.4	-0.9	1.2	7.8	4.2	**6.4**	**10.7**	**10.0**
North Asia	**2.4**	**2.6**	3.1	0.6	3.3	2.9	2.1	-1.0	1.0	0.6	2.5	-1.9
	multi-model				perturbed parameters				stochastic physics			

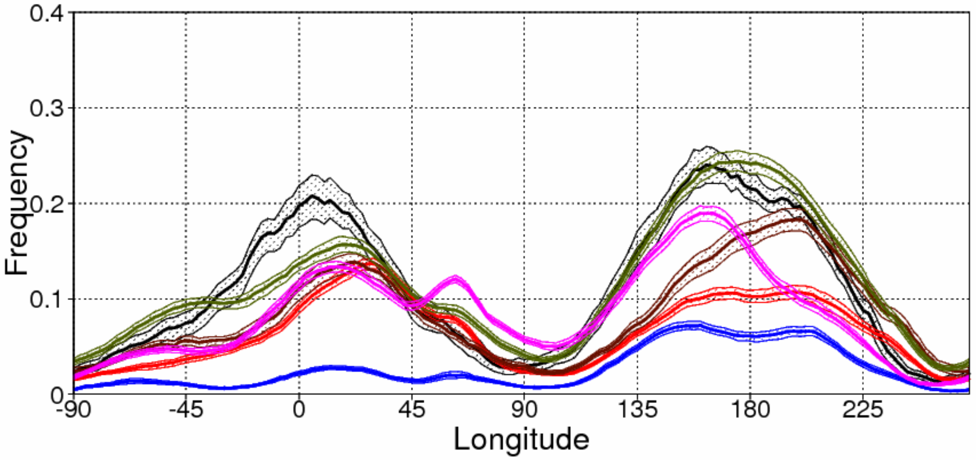
Commonality of systematic errors

Northern Hemisphere DJF blocking frequency for 1-month lead seasonal hindcasts for the ECMWF, Météofrance, Met Office, IfM and INGV forecast systems over the period 1981-2005 compared to ERA40/ERAInt. Results are for the Tibaldi and Molteni index (reversal of the meridional gradient of Z500). 95% intervals are shown.

JJA

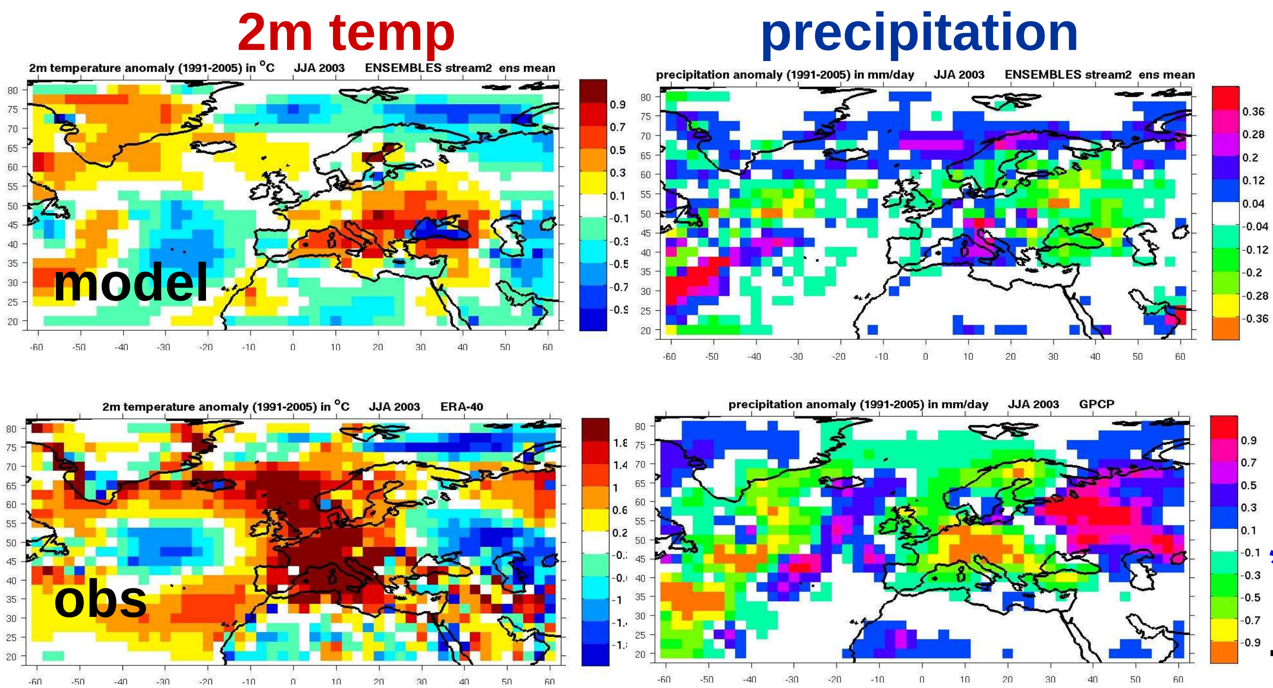


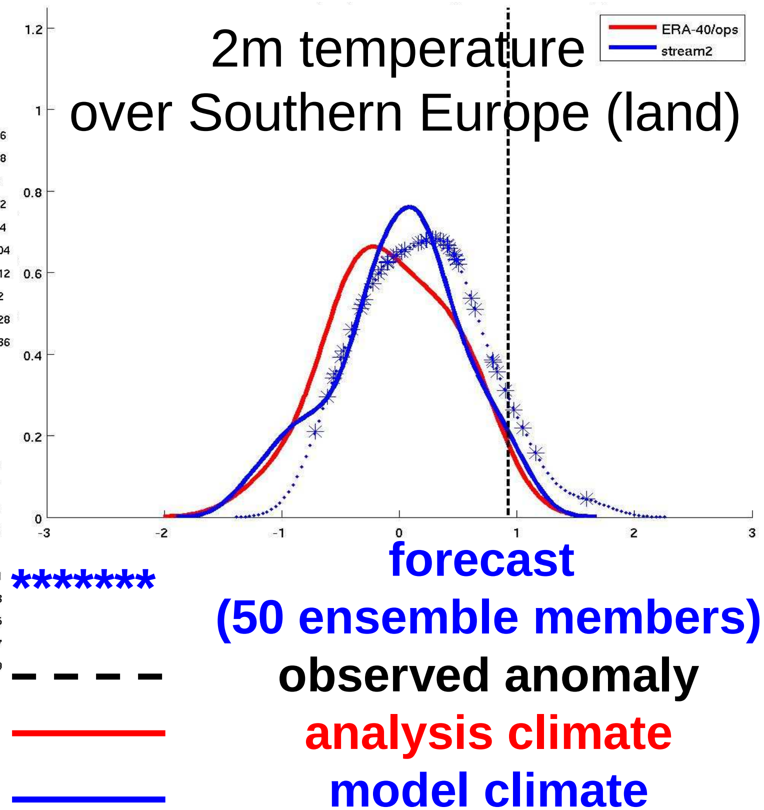
DJF



Model improvement

ECMWF ENSEMBLES operational seasonal prediction for summer 2003 with May start date. Anomalies wrt period 1991-2005.



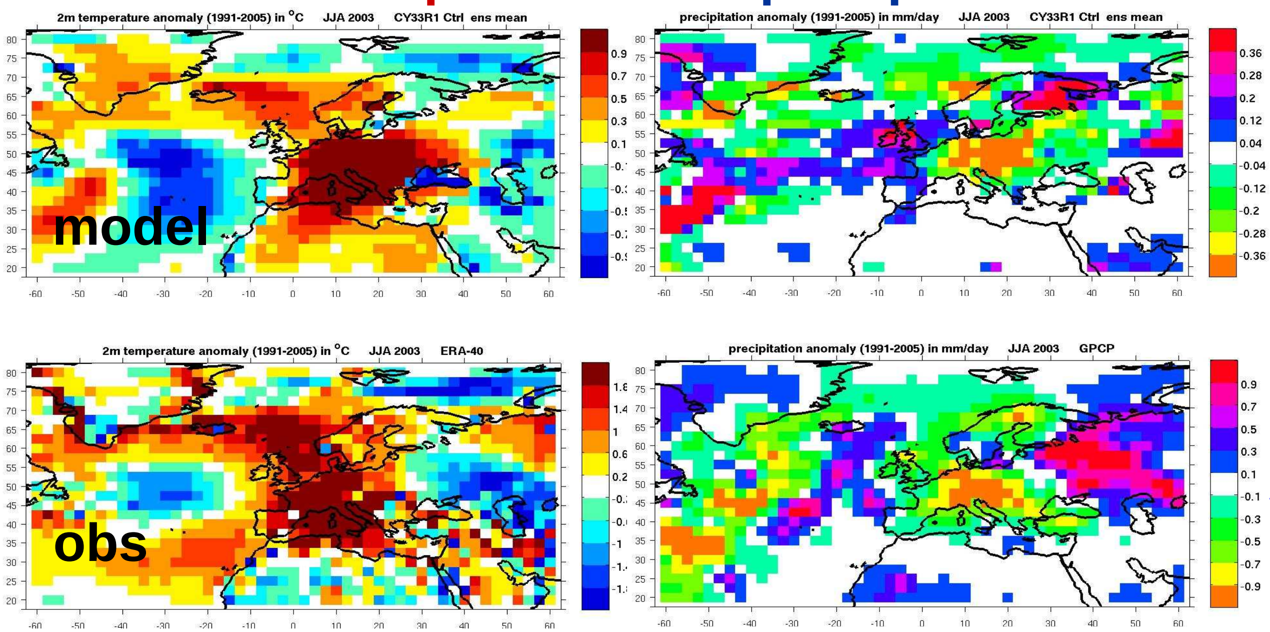


From Antje Weisheimer

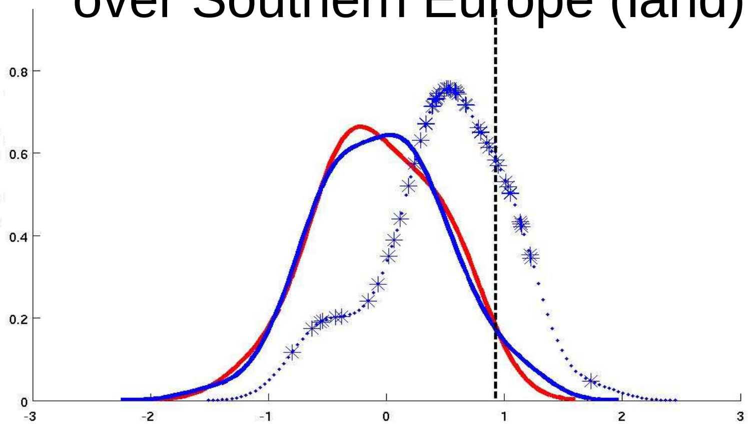
Model improvement

Seasonal prediction with improved ECMWF system (changes in radiation, soil scheme and convection) for summer 2003 with May start date. Anomalies wrt period 1991-2005.

2m temp **precipitation**



2m temperature
over Southern Europe (land)



******* **forecast (50 ensemble members)**

– – – – **observed anomaly**

—— **analysis climate**

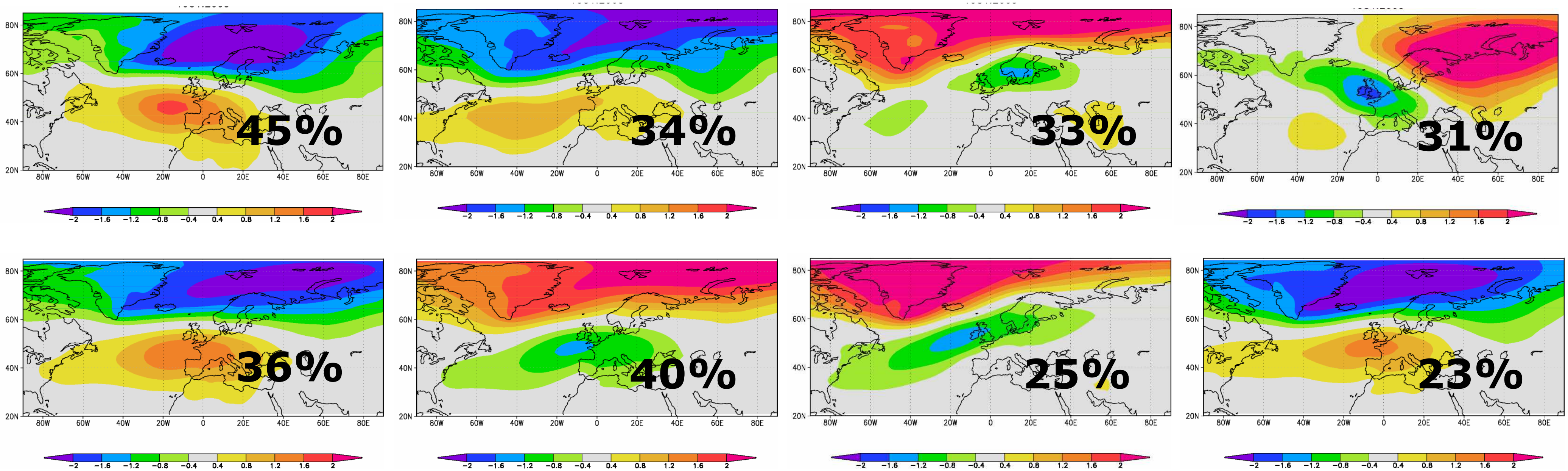
—— **model climate**

From Antje Weisheimer

Modes of variability: NAO

Leading EOF of SLP over the region 20°-85°N,90°W-90°E for NCEP/NCAR R1 (top row) and one-month lead System 3 re-forecasts (bottom row). Variance percentage in brackets.

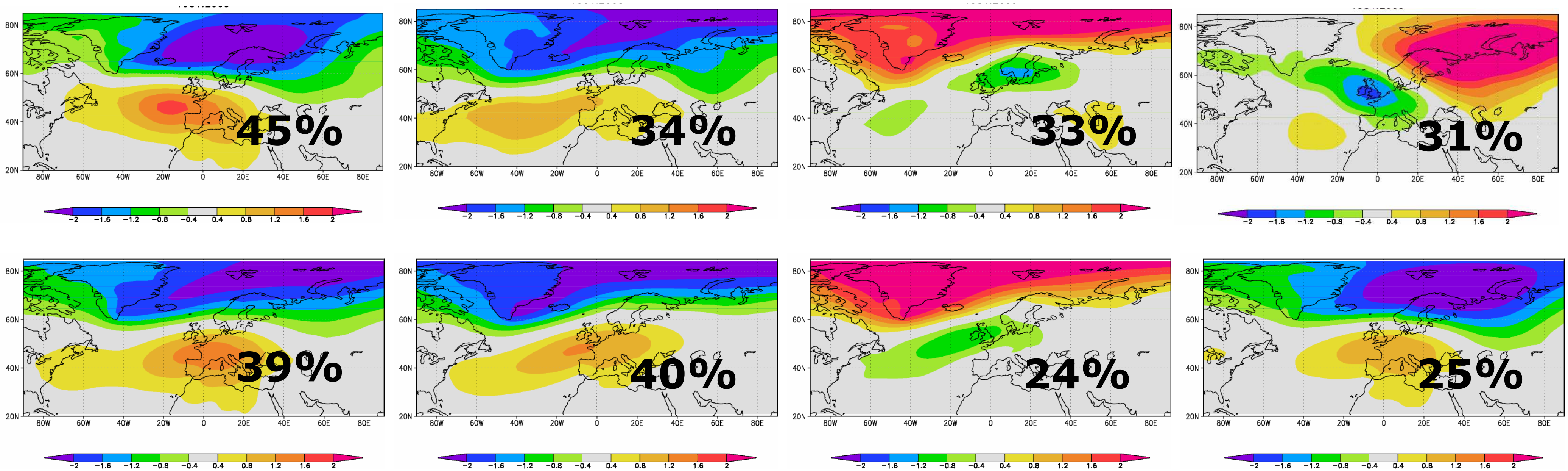
DJF **MAM** **JJA** **SON**



Modes of variability: NAO

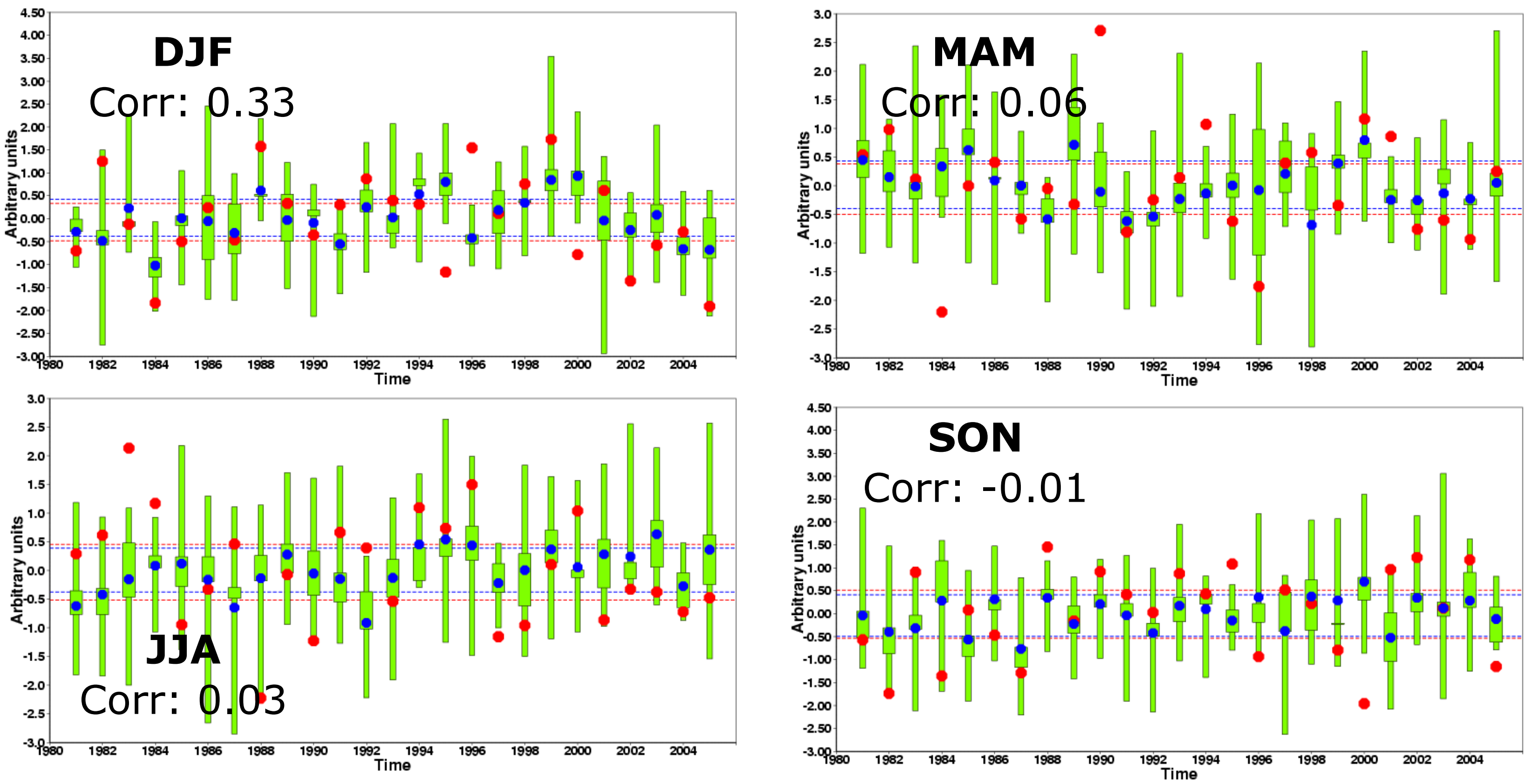
Leading EOF of SLP over the region 20°-85°N,90°W-90°E for NCEP/NCAR R1 (top row) and three-month lead System 3 re-forecasts (bottom row). Variance percentage in brackets.

DJF **MAM** **JJA** **SON**



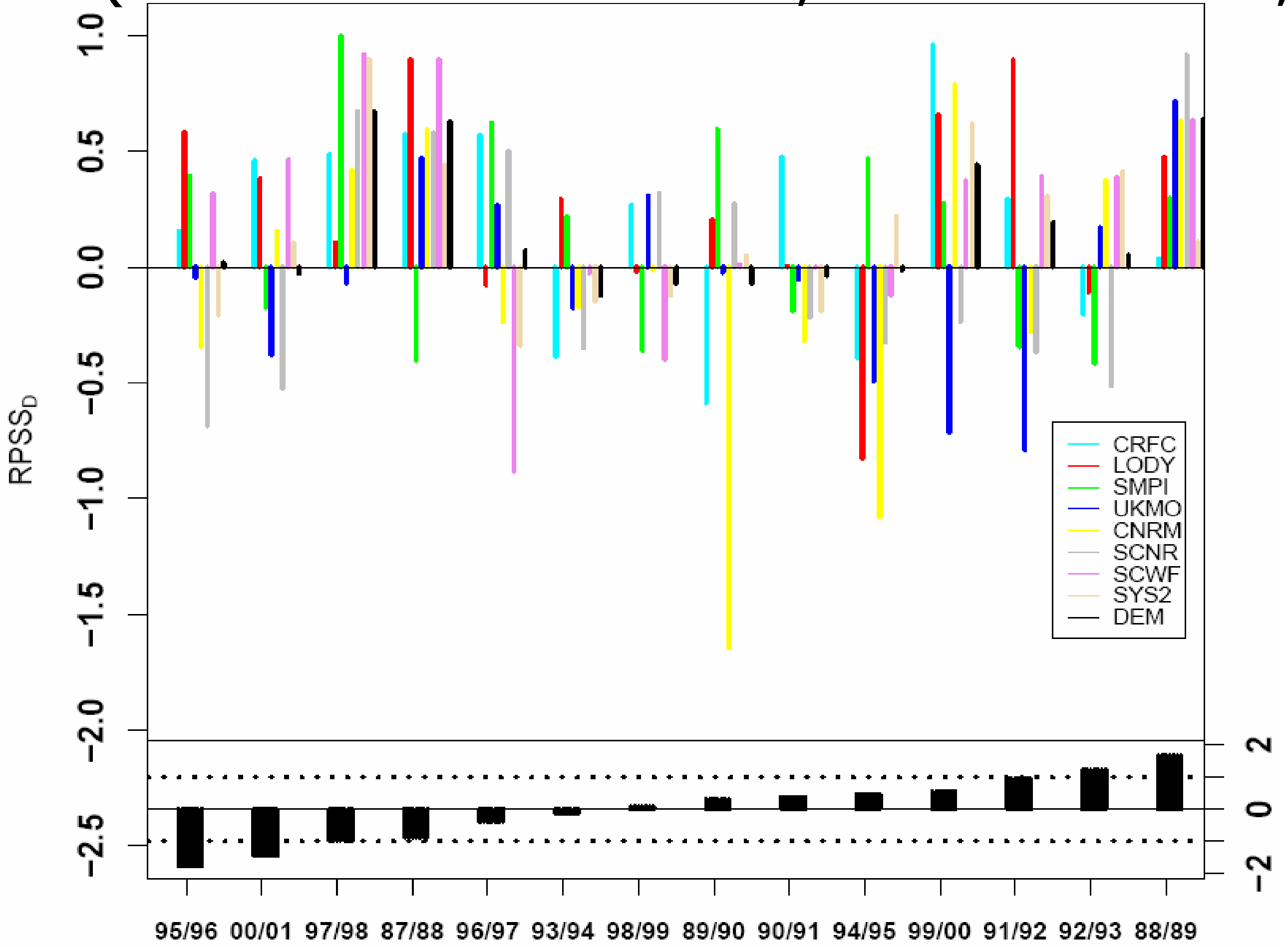
Modes of variability: NAO

System 3 NAO predictions over 1981-2005. The green box-and-whisker show the ensemble range, the blue dot the ensemble mean and the red dot the ERA40/ERAInt value.



Prediction of extreme NAO

ECMWF System 2 and DEMETER NAO DJF forecasts (November start date, 1-month lead, 1987-2001).



$RPSS_D$ for tercile categories

Observed NAO

Müller et al. (2005)

NAO predictions

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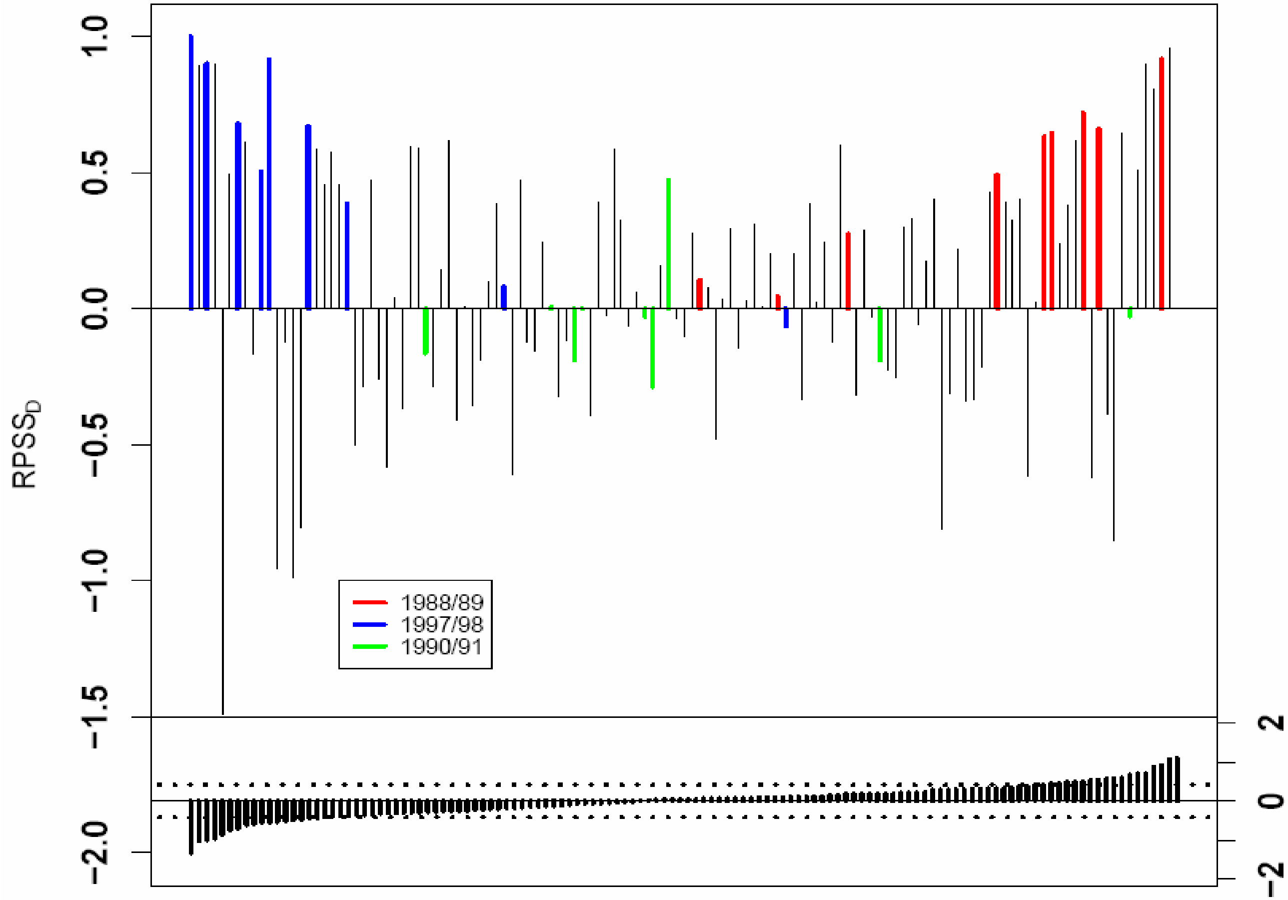
ECMWF System 2 and DEMETER NAO DJF forecasts (November start date, 1-month lead, 1987-2001).



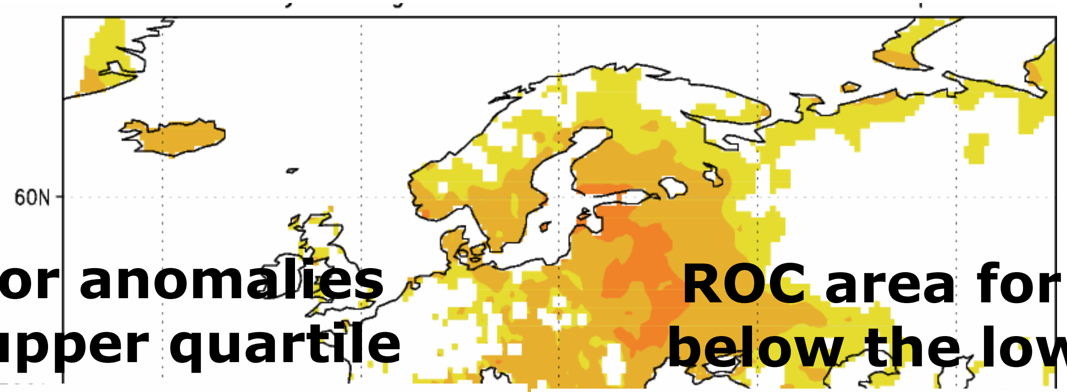
$RPSS_D$ for tercile categories

Predicted NAO

Müller et al. (2005)

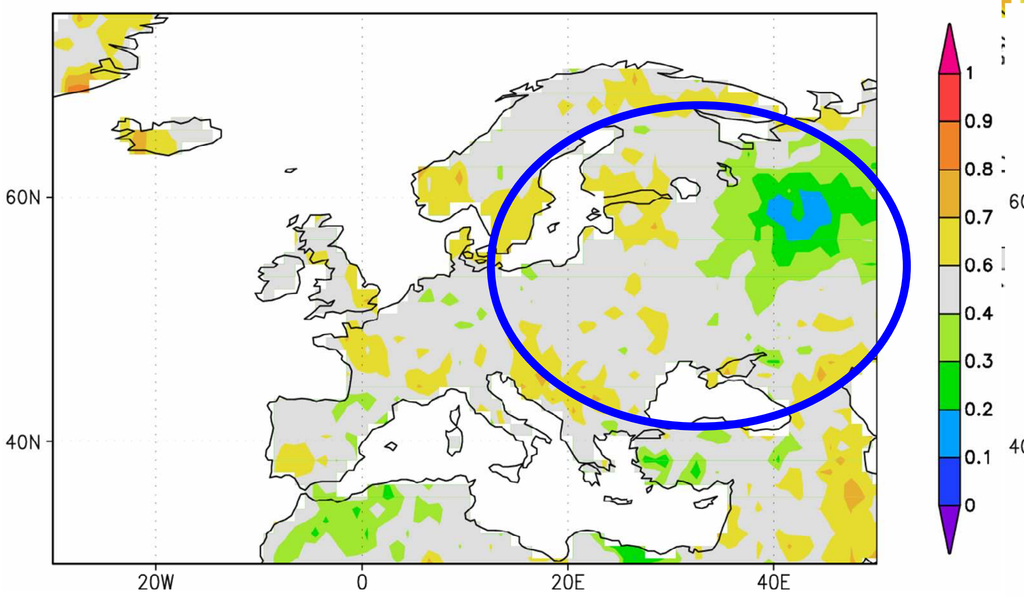
Sources of predictability: snow cover

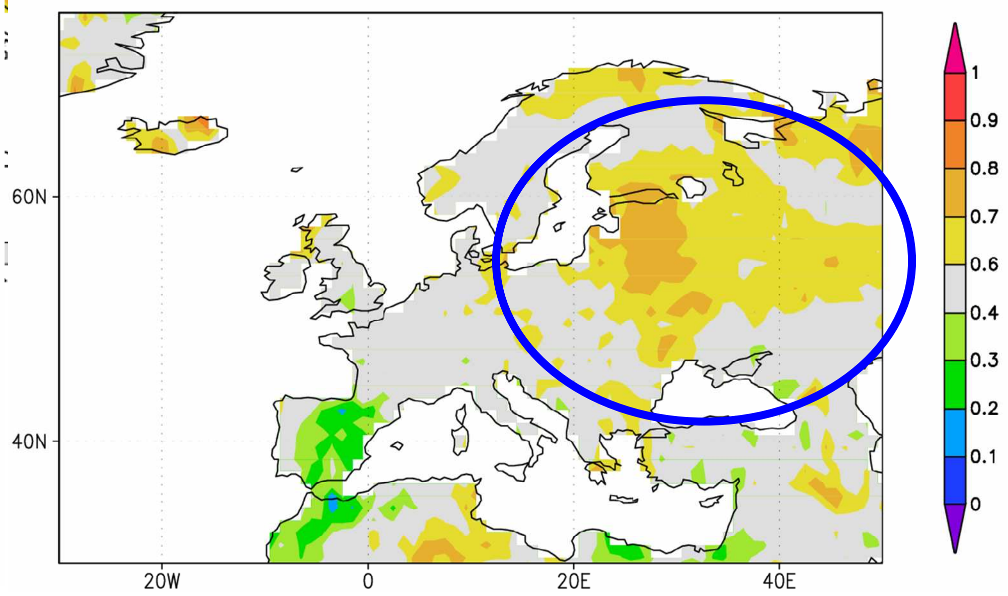
Correlation for System 3 MAM temperature over 1981-2005 wrt to GHCN temperature (after Shongwe et al., 2007).



ROC area for anomalies above the upper quartile

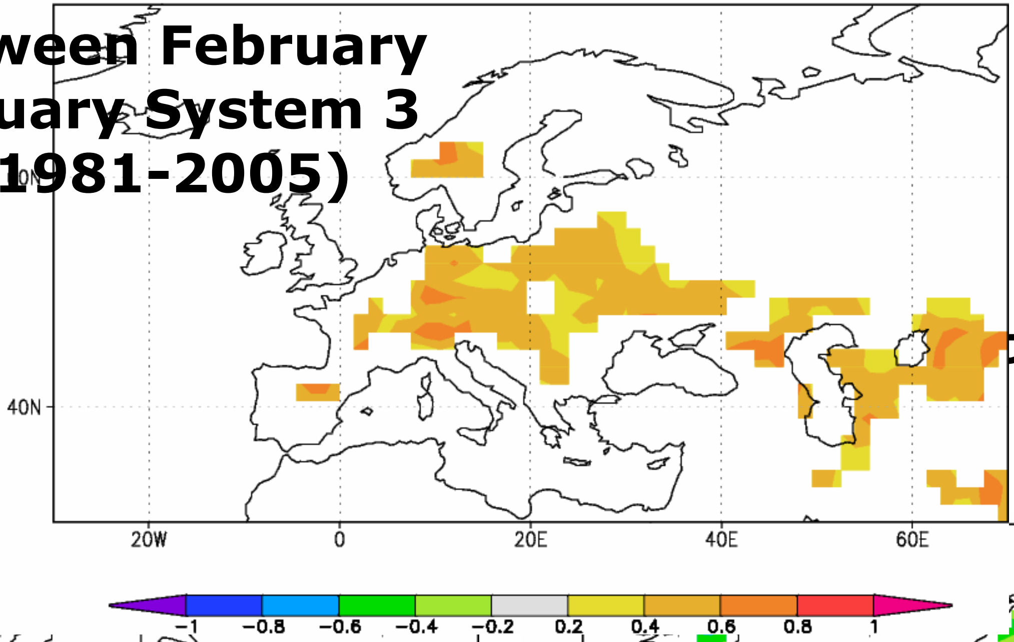
ROC area for anomalies below the lower quartile





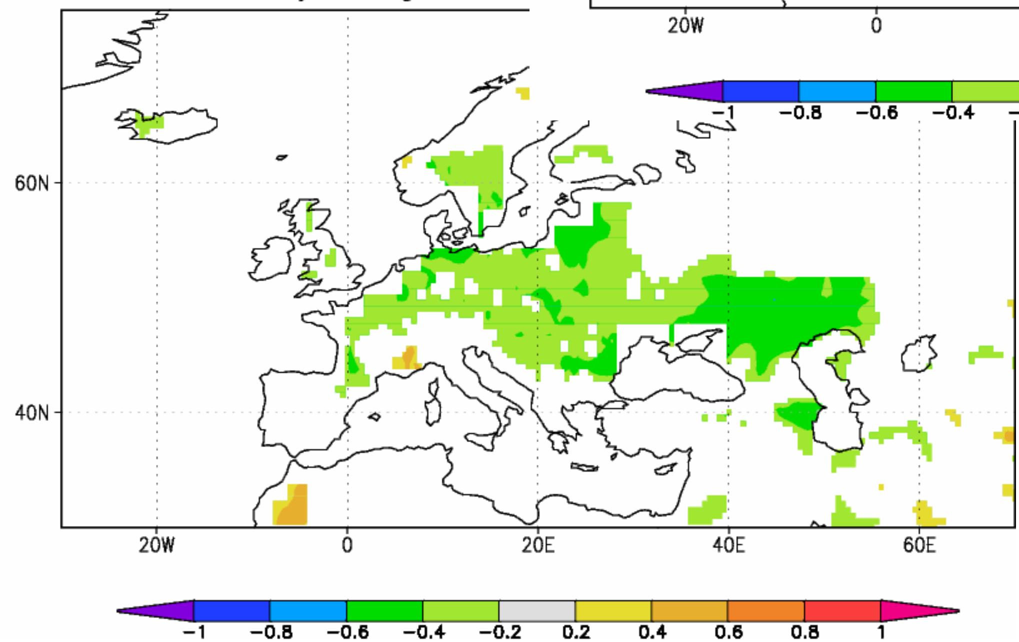
Sources of predictability: snow cover

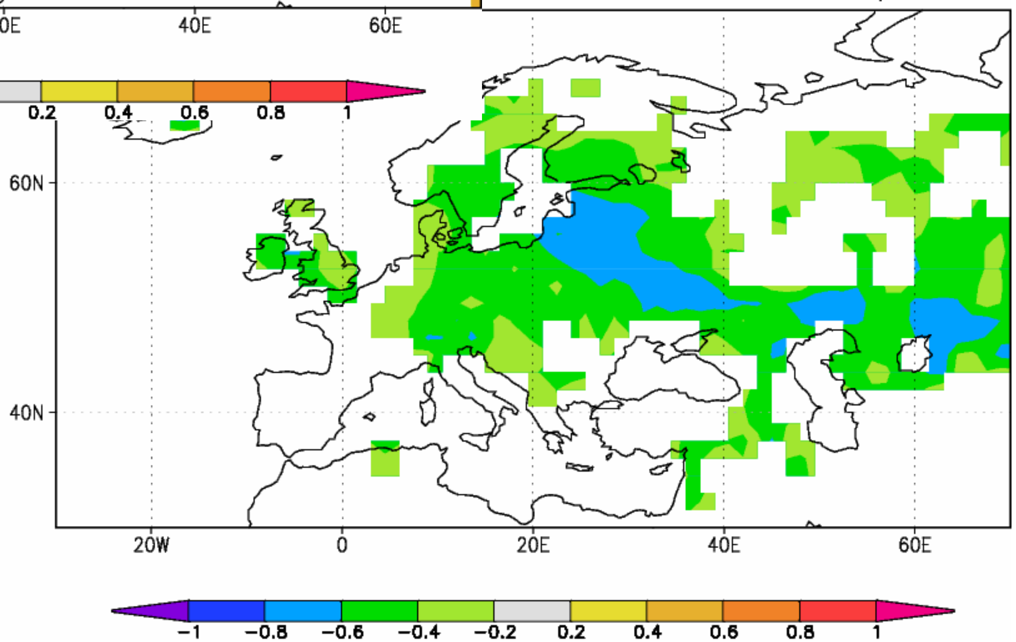
Correlation between February NOAA and February System 3 snow cover (1981-2005)



Correlation bet
NOAA snow co
GHCN temp. (

tween February
cover and MAM
(1981-2005)





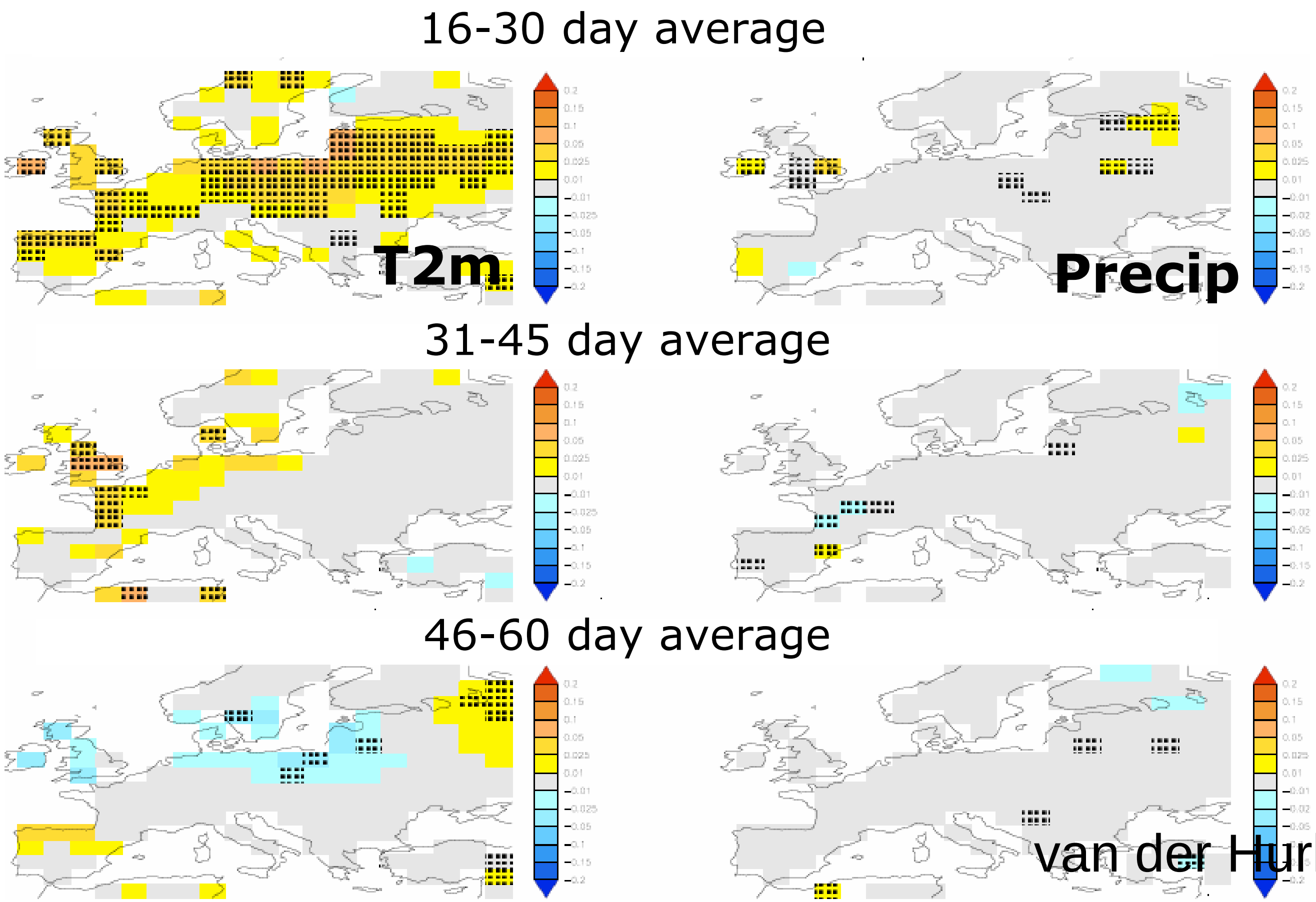
Sources of predictability: soil moisture

GLACE2 multi-model experiment: 10-member ensembles, 10-start dates (1st April to 15th August) per year over 1986-1995; Series 1 (2) with realistic (unrealistic) soil moisture initialization.

acronym	model resolution	remark
CCCMA	2.8° × 2.8°	
COLA	1.9° × 1.9°	version 3.2
COLA_CAM	1.4° × 1.4°	NCAR CAM 3.5
ECHAM	1.9° × 1.9°	version 5; initial soil moisture series 1 derived from different land surface model simulations
ECMWF	1.1° × 1.1° (*)	Integrated Forecasting System (IFS), ocean-atmosphere coupled
FSU	1.9° × 1.9°	Soil initialization from data assimilation suite
KNMI	1.1° × 1.1° (*)	as ECMWF, with prescribed sea surface temperatures
NCAR	2.8° × 2.8°	CAM 3.0
NCEP	0.9° × 0.9°	GFS/Noah
NSIPP	2.5° × 2°	GMAO forecasting system

Sources of predictability: soil moisture

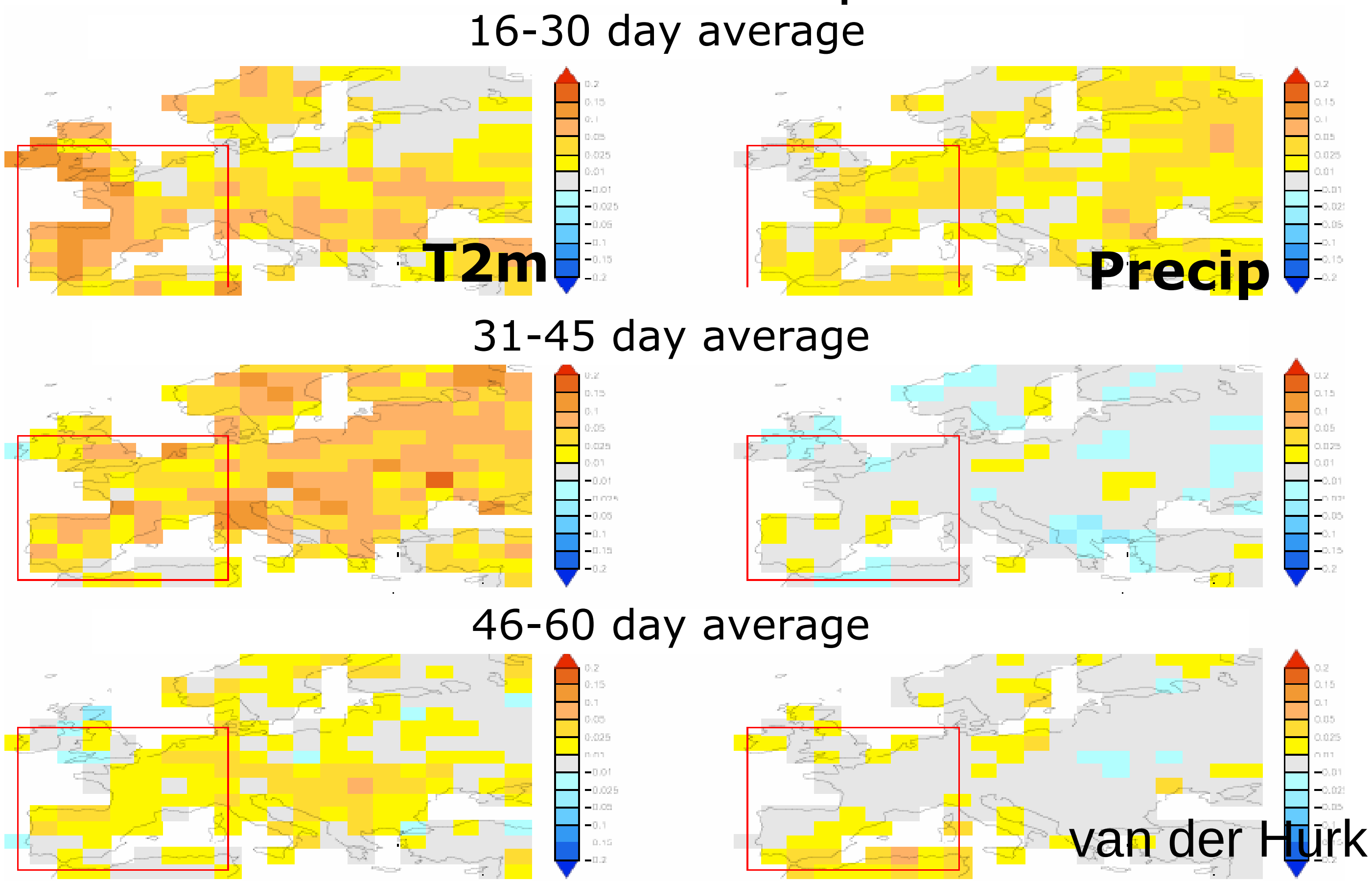
GLACE2 multi-model R2 difference between Series 1 and Series 2. Grid points with statistically significant differences with 98% confidence level are dotted.



van der Hurk et al. (2011)

Sources of predictability: soil moisture

GLACE2 multi-model R2 difference between Series 1 and Series 2 for the grid points that produce a skill improvement in the Southwest Europe red box.



van der Hurk et al. (2011)

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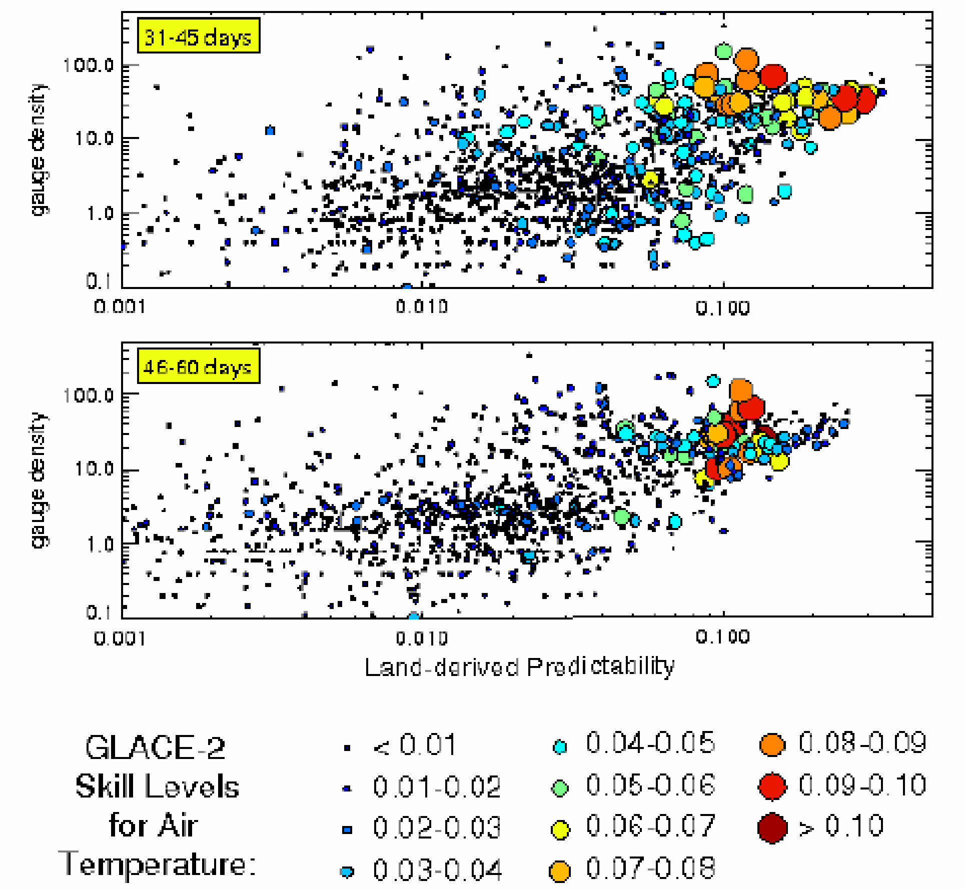
Sources of predictability: soil moisture

GLACE2 multi-model Series 1 skill as a function of the R2 difference between Series 1 and Series 2 (horizontal axis) and the gauge density (vertical axis).



Koster et al. (2010)

Sources of predictability: soil moisture

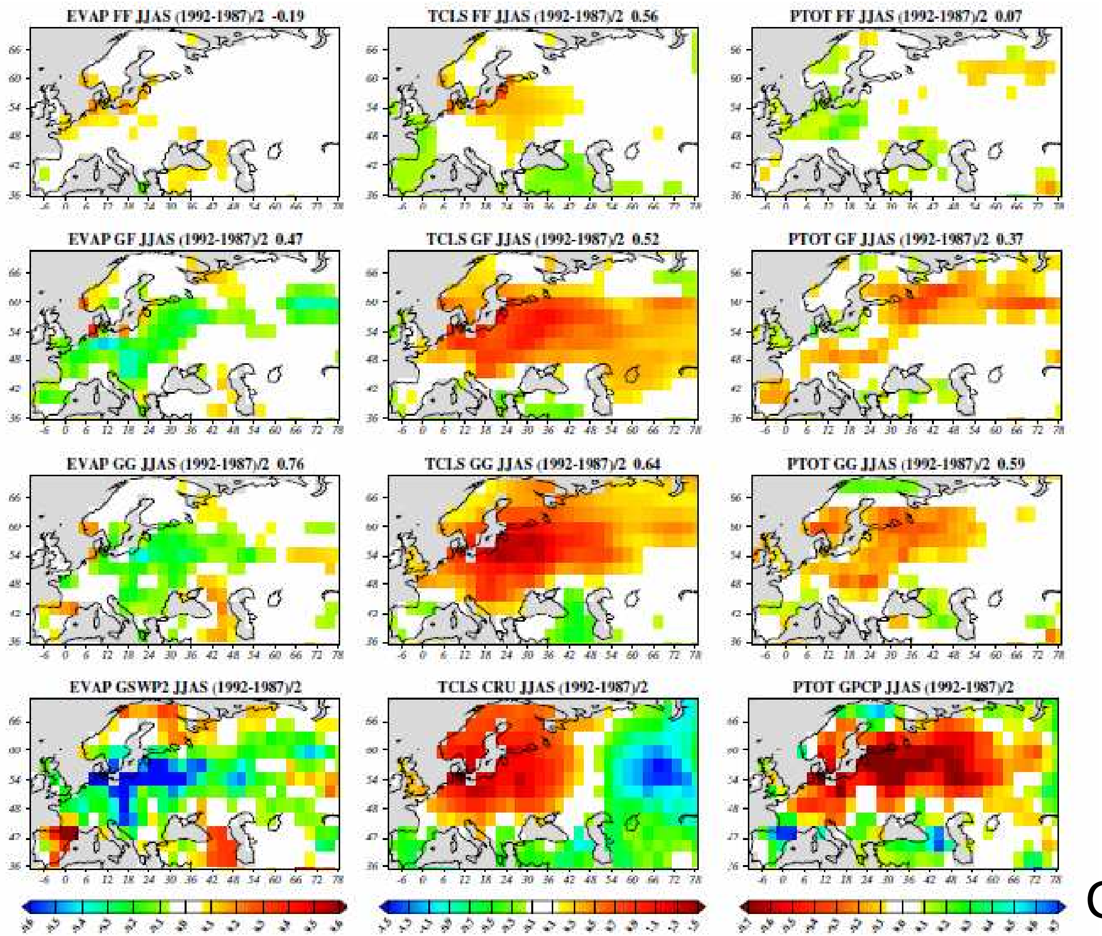
Difference between summer (JJA) 1992 and 1987 anomalies of three ARPEGE SST-forced ensembles and observations.

Uninitialized, interactive SM

SM relaxed to GSWP2

Initialized, interactive SM

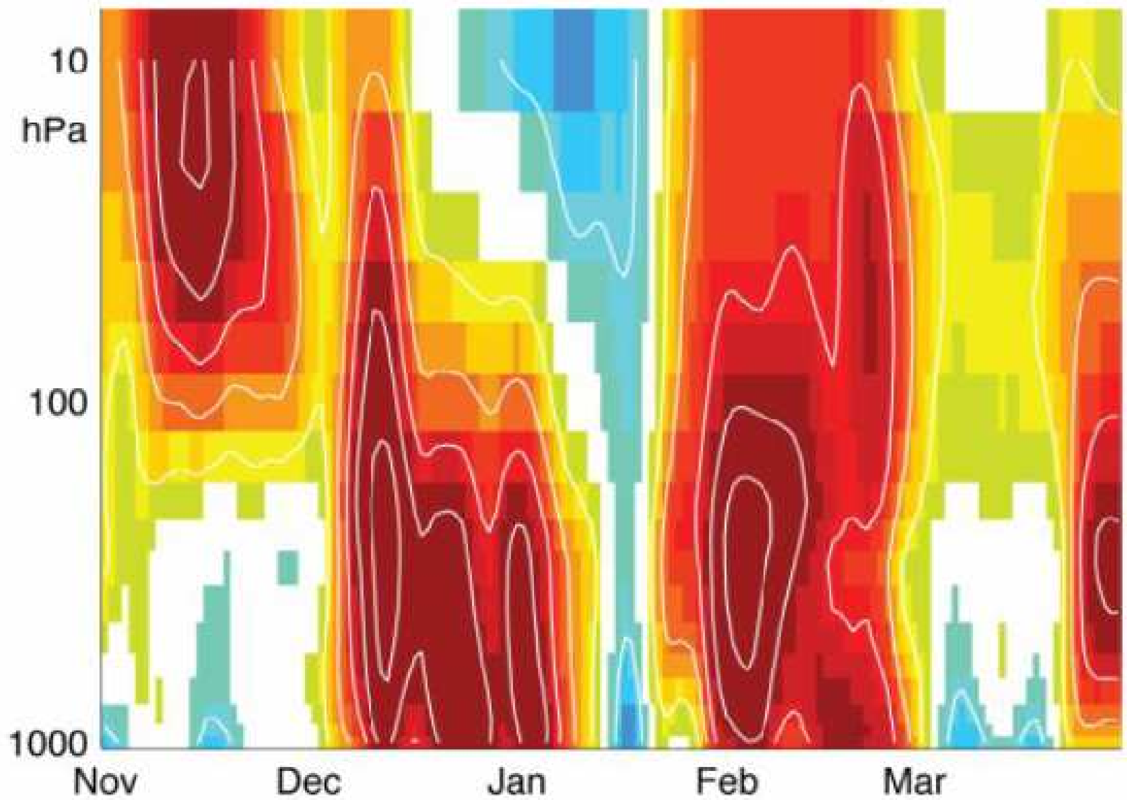
ISBA GSWP2 evap, GPCP precip and CRU temp



Conil et al. (2009)

Sources of predictability: stratosphere

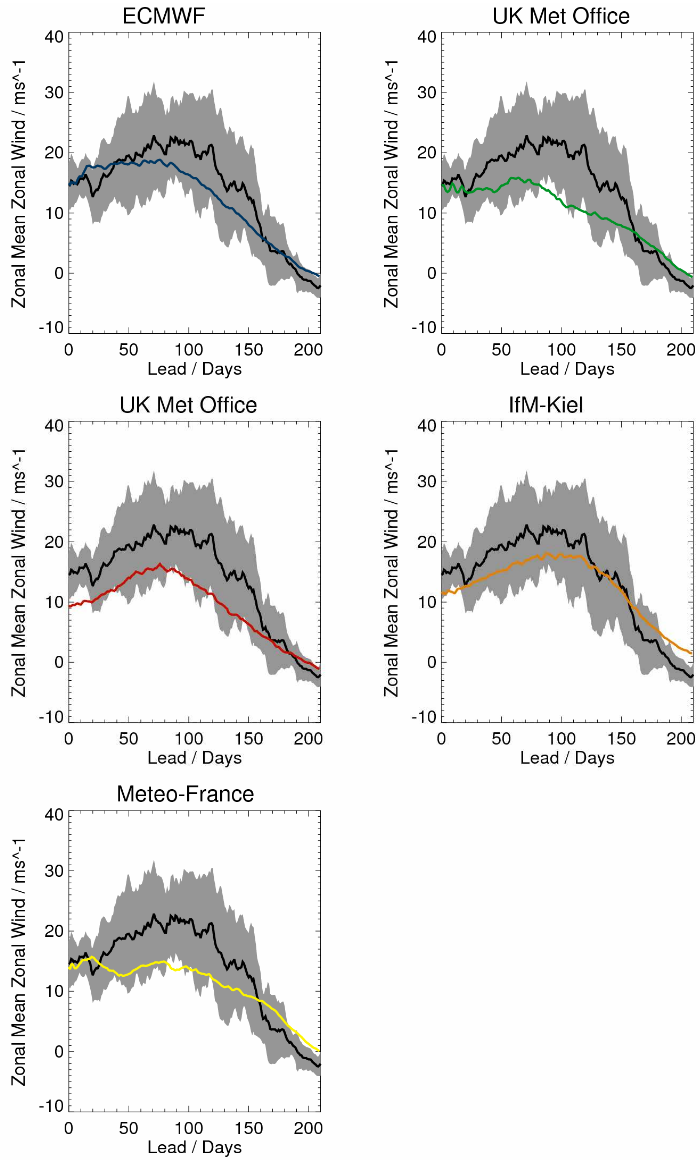
Five-day running mean of standardized geopotential height polar cap anomalies from NCEP/NCAR R2 for 2009-10 winter. Red (blue) for positive (negative) anomalies and solid white contours for each 0.5 standard deviation.



Sources of predictability: stratosphere

Daily evolution of the zonal mean of the 50-hPa zonal wind for the ENSEMBLES Stream 1 hindcasts with November start date (the horizontal axis runs from the 1st of November to the 31st of May). Results are averaged over 1991-2001. Black lines are for the ERA40 climatology (with shaded region covering ±σ).

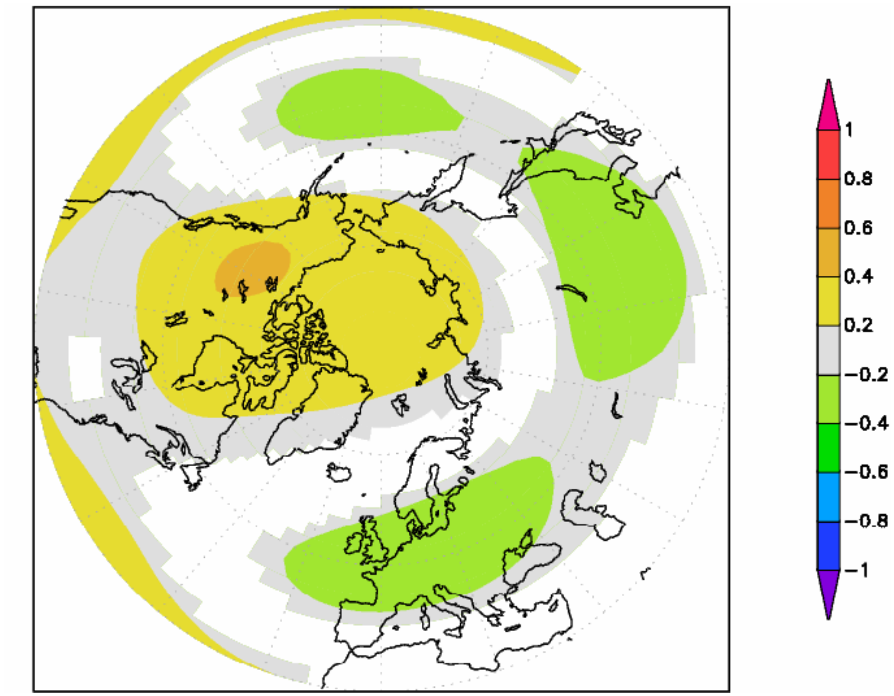
Every forecast system underestimates the mean wind. The same happens with the intraseasonal variability that prevents stratospheric sudden warming events from happening with the correct frequency and amplitude.

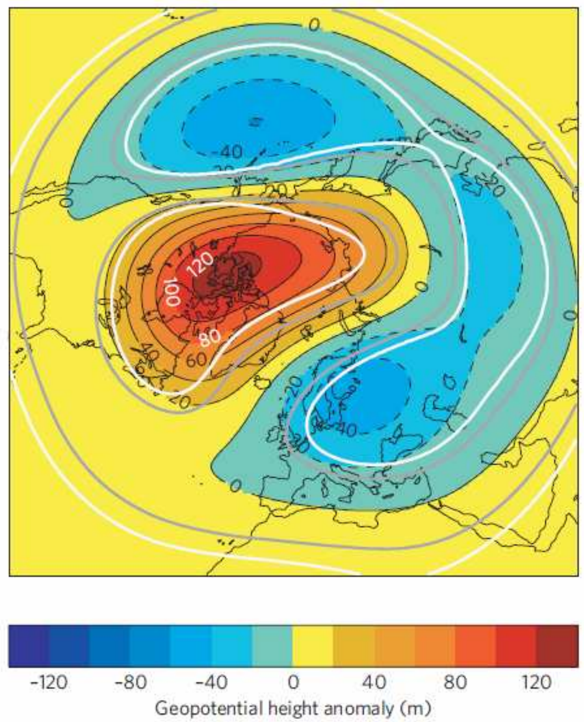


Maycock et al. (2009)

Sources of predictability: stratosphere

(Left) Correlation between DJF 50-hPa geopotential height and predicted Niño3.4 SST time series with the November start date. (Right) Difference in DJF 46-hPa geopotential height between El Niño and non-El Niño events in HadGAM1.

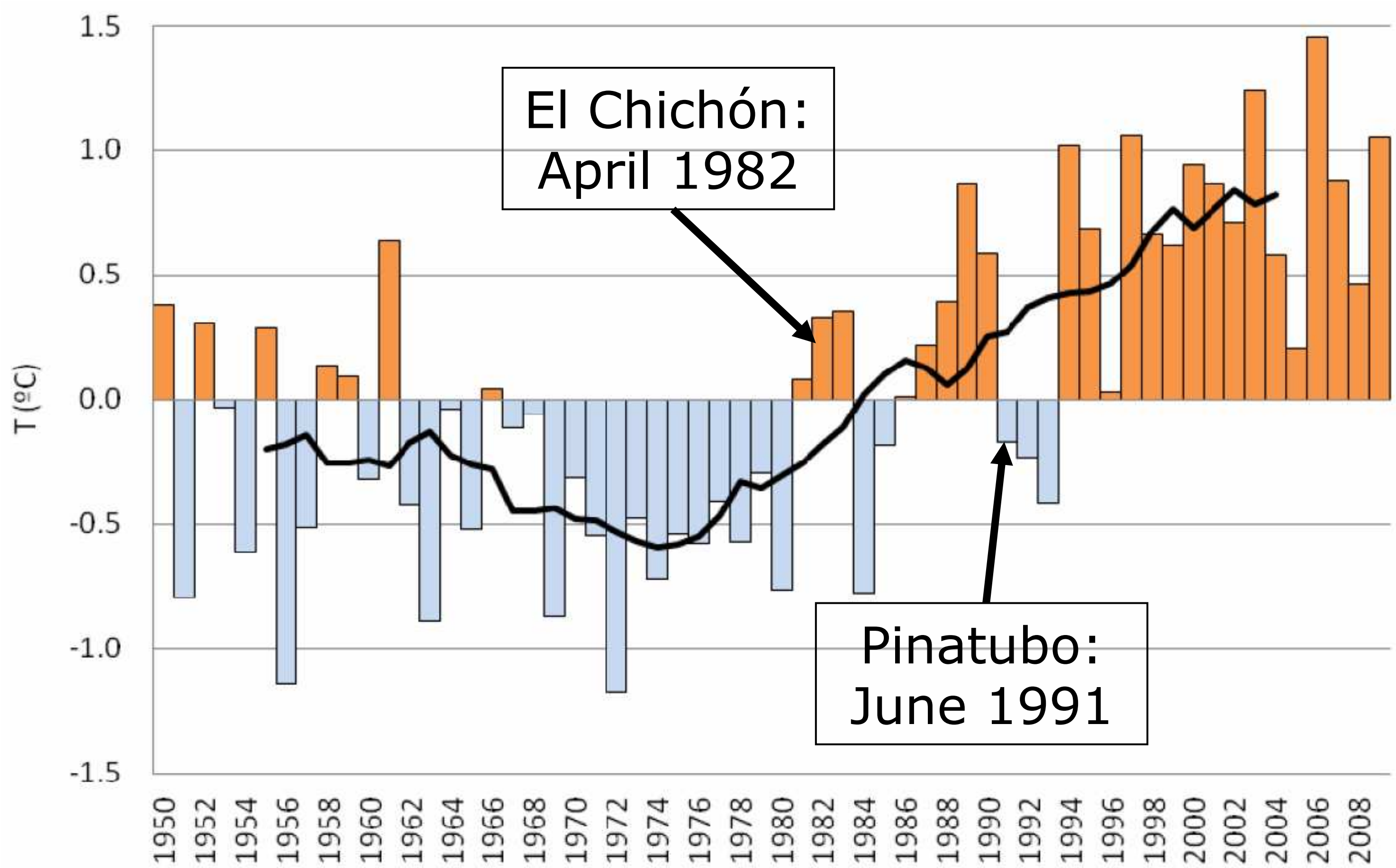




Ineson and Scaife (2009)

Sources of predictability: volcanoes

Annual-mean air temperature anomalies (wrt to 1950-2009) for 17 stations over Catalonia (northeast Spain).



MeteoCat

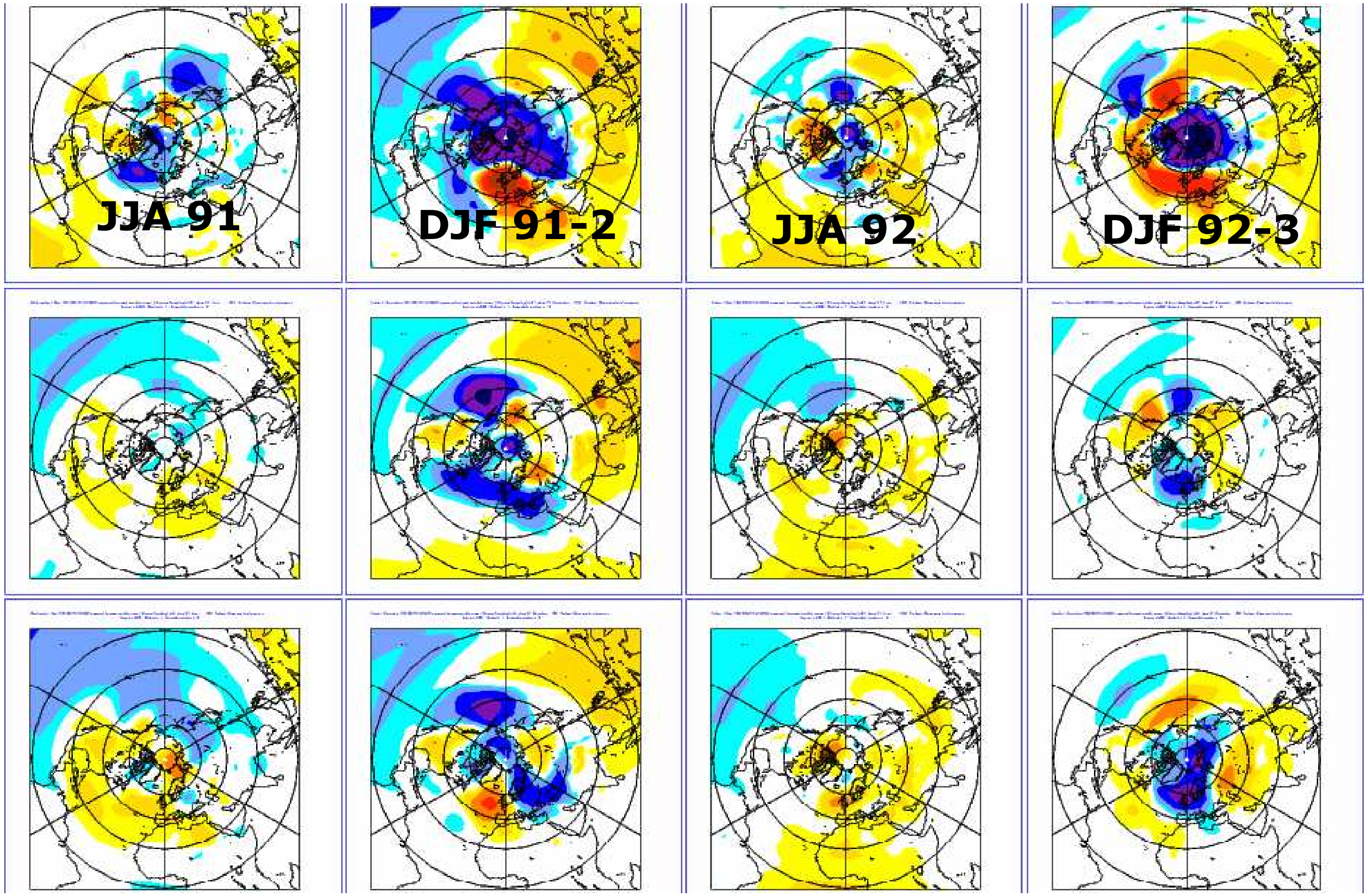
Sources of predictability: volcanoes

Mean sea level pressure anomalies wrt 1981-2001 for ERA40 and two sets of one-month lead EC-Earth seasonal hindcasts.

ERA40

With Pinatubo volcanic aerosol

Without Pinatubo volcanic aerosol



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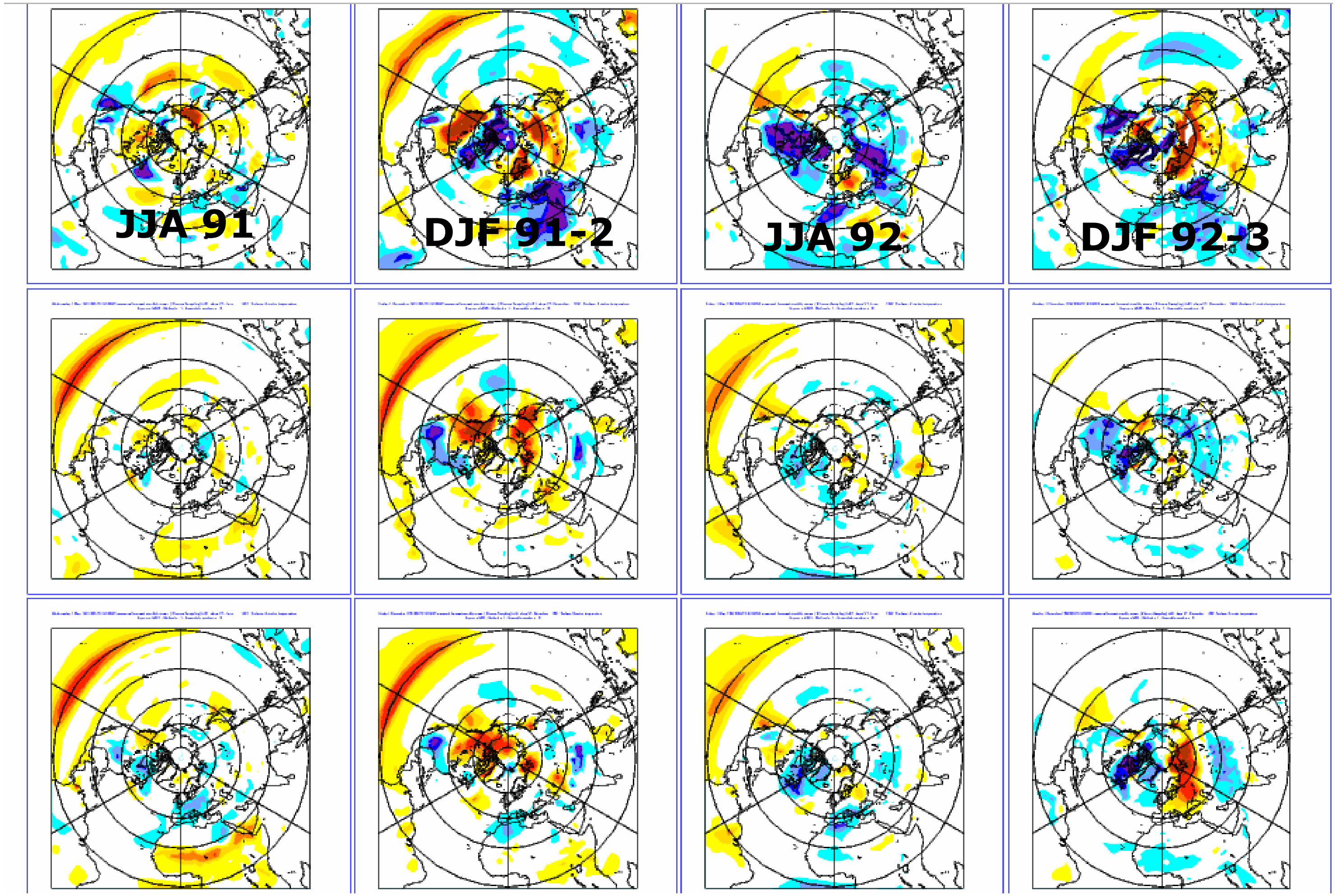
Sources of predictability: volcanoes

Temperature anomalies wrt 1981-2001 for ERA40 and two sets of one-month lead EC-Earth seasonal hindcasts.

ERA40

With Pinatubo volcanic aerosol

Without Pinatubo volcanic aerosol



Summary

- Substantial systematic error, including lack of reliability, is still a fundamental problem in dynamical forecasting and forces *a posteriori* corrections to obtain useful predictions. Don't take model probabilities as true probabilities.
- Initial conditions are still an important issue.
- Estimating robust forecast quality is difficult, but there are windows of opportunity for reliable skilful predictions, and there is always the anthropogenic warming.
- There is a potential coming from methods that deal with model inadequacy (e.g. multi-model ensembles).
- Many more processes to be analyzed: sea ice, stratosphere, soil moisture, anthropogenic aerosols, …

Some final thoughts

- In the end we need trustworthy models but model development is a slow process.
- Users will require calibration and can provide feedback on the presentation of forecast information.
- Seasonal forecasting over Europe would benefit from a coordinated effort to improve the forecast systems and to combine climate information from different sources.